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Featuring

Engineering Geology as Applied to Location of Tunnels and Dams

Sludge Digestion

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JOURNAL OF THE

BOSTON SOCIETY OF CIVIL ENGINEERS

Volume XVI JANUARY, 1929 Number 1

ENGINEERING GEOLOGY AS APPLIED TO LOCATION OF TUNNELS AND DAMS

(Papers and Discussions presented at a meeting of the Boston Society of Civil Engineers, November 21, 1928)

SUBSURFACE EXPLORATIONS FOR THE LOCATION OF THE WACHUSETT-SWIFT TUNNEL

By Frank E. Fahlquist *

The bringing of additional water supply to metropolitan Boston involves the construction of approximately 25 miles of continuous tunnel, 13 miles of which are already under construction; the remaining 12 miles consisting of a proposed extension to the proposed Swift River Reservoir. The portion now under contract involves the construction of a tunnel through rock from Oakdale, at the west end of the Wachusett Reservoir, to the Ware River in the vicinity of Coldbrook. The flood flows of the Ware River will be diverted into the tunnel at this point, namely, Shaft 8, and stored in the Wachusett Reservoir. The proposal of an extension of the tunnel westward, from Shaft 8 to the contemplated Swift River Reservoir, will make a waterway connection between the present and future supplies of the district, the water ultimately reaching the consumer by a tunnel and aqueduct already in service. The tunnel will be of a horseshoe section, 11 feet wide and 12 feet 9 inches high, over the greater part of its length. Where great pressures are encountered a circular section 12 feet 9 inches in diameter will be used. The cross-sectional area has been designed to give a capacity of 500 million gallons

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* Assistant Engineer, Metropolitan District Water Supply Commission.

daily upon complete development of the sources to the west of the Wachusett area.

As it was desirable to have the tunnel constructed in rock for its entire length, rather extensive subsurface explorations were carried on, and it is the purpose of this paper to present some of the data obtained and deductions made from them. Some of the gentlemen present are familiar with the paper "Engineering Geology of the Catskill Water Supply" presented before the American Society of Civil Engineers by Dr. C. P. Berkey and Mr. James F. Sanborn. The geological conditions encountered on the Catskill project were many and varied, and in general covered the entire field of geological problems involved in construction work of this nature. The speaker cannot go into a complete description of the geological problems involved in the construction of the Wachusett–Swift Tunnel, as complete data are not yet available, but will confine himself to the relationship between topographic forms now existing and past geologic processes, and their applications to the problems of tunnel alignment, in direction and in depth.

Nature of Country Traversed by Tunnel

The tunnel crosses what is known as the central upland of Worcester County plateau. Geologists postulate that during the cretaceous period this section of Massachusetts was worn down practically to sea level, establishing a base level of erosion, now called the cretaceous peneplain, having an average elevation between 1,000 and 1,200 feet above sea level. Standing above the general level of this area are isolated sections of considerably higher elevations called monadnocks, such as Mount Wachusett, elevation 2,000, and Asnebumskit Hill, elevation 1,400. After the development of this base level of erosion, the sluggish streams were rejuvenated by a gradual uplift and warping of the earth's crust, and then began a new cycle, that of dissecting the peneplain, which process is still continuing.

It is an accepted fact by all students of geology that the latter part of the quaternary period was marked by a period of intense continental glaciation, which extended across the North American continent from ocean to ocean, and on the Atlantic seaboard as far south as northern New Jersey. The ice sheet, on its advance, overtopped the highest mountains in New England, and modified the then existing topography by scouring the deeply disintegrated rock. Upon the retreat of the ice sheet large quantities of the by-products of disintegrated rock and ice abrasion which had been frozen into the ice were deposited over the country in various forms, forming a surface topography which in some cases has very little relation to the bedrock topography. An understanding of bedrock conditions along the tunnel line involved an understanding of the probable mechanical action and forces of the ice sheet and the topographic forms left upon its retreat.

ROCK FORMATIONS AND GEOLOGICAL STRUCTURES

The rocks along the line are wholly of the metamorphic and igneous types. There is a great deal of variety in character not only in the rocks of different formations, but in the rocks from the same formation. At the east end is found a plainly foliated rock, grading between a quartzite or quartzitic schist and quartz mica phyllite. Between Shafts 3 and 6 occur the most extensively developed single type, — a quartz mica schist of medium grain. Intruded into these two types is a biotite granite, which in its simplest state composes the granite formation. Over wide areas the resultant rock is a mixture of the invading granite and the parent or overlying schists, so that the type is essentially a mixed injection schist.

It is clear that the phyllites were derived from argillaceous sediments, and the quartz mica schist from more quartzose sediments. After the consolidation of these sediments into rock they were intruded and intimately injected and soaked by igneous magmas, chiefly granite, and reacted upon in various degrees. The distribution of these rocks in broad and narrow belts has had a decided part in the formation of the present topography. As is usual, the softer rocks, the phyllites and mica schists, have been eroded more readily than the more resistive quartzitic schists, with the result that in almost all cases the major valleys lie within the mica schist belts. The geologic structure over wide areas is rather flat. The average strike of the formations is in a general north-south direction, with the schists dipping towards the east and the west. Even where the invading granite has wholly or partially absorbed the overlying schist the structure can be faintly recognized. The flattest structure is found in the middle area, between Shafts 3 and 6, where for a distance of four and one-half miles the structure does not exceed ten degrees from the horizontal. The rock here is of the quartzitic and quartz mica schist variety, and has been affected in only a small degree by the invading granite.

To the east of this section the rock is of the mixed injection schist type, and has been folded and crushed, which has made the rock more susceptible to weathering by circulating underground waters. The cleavage developed in the mica schist is near the horizontal, and is the source of the trouble encountered to date through excessive scaling in the tunnel arch. To the west, especially in the vicinity of Shaft 7, the structure is somewhat stronger and shows a greater amount of the granite mixed with the schist. The underground circulation of water is confined to the joints in the rock, except in that portion of the tunnel at Shaft 3. At this point, due to the crushing of the rock, the water is not confined to any particular set of joints, but seems to escape from a great number of smaller fractures.

POSSIBLE ANCIENT DRAINAGE COURSES

A study of the topographic map revealed that there were, at least, six ancient drainage courses, now partly or wholly unoccupied by rivers, which cross the tunnel line. As all of these crossed the line at practically right angles it was necessary to determine at what elevations their water-gaps exist in the topography at the present time, and to eliminate those which had such high elevations as to make the rock clearance above the tunnel more than ample. A summary of these courses follows:

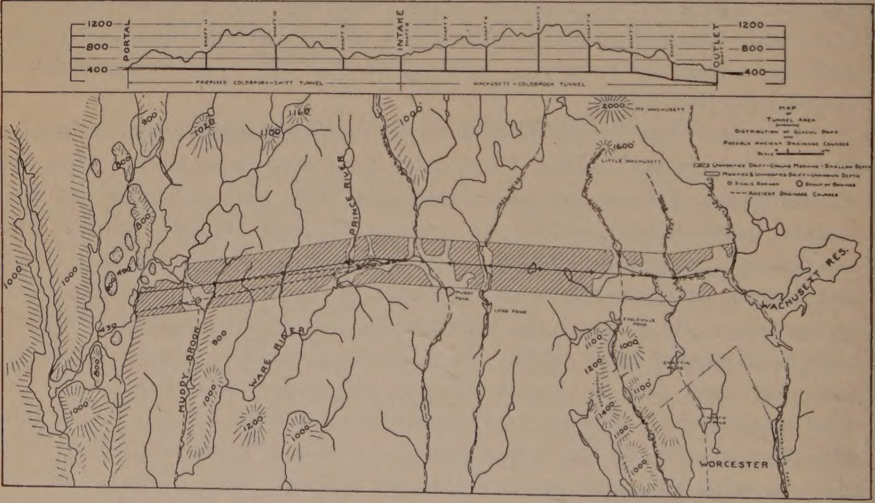
1200
800
400
PORTAL
INTAKE
OUTLET
1200
800
400
MAP OF TUNNEL AREA SHOWING DISTRIBUTION OF GLACIAL DRIFT AND POSSIBLE ANCIENT DRAINAGE COURSES
Unsorted Drift—Ground Moraine—Shallow Depth
Modified & Unsorted Drift—Unknown Depth
Single Boring
Group of Borings
Ancient Drainage Courses
PRINCE RIVER
MUDDY BROOK
WARE RIVER
WACHUSETT RES.
WORCESTER
1166
2000
1600
1200
1000
900
800

FIG. 1.—DISTRIBUTION OF GLACIAL DRIFT AND POSSIBLE ANCIENT DRAINAGE COURSES

1. Stillwater River, through the Muddy Brook gap at elevation 400±, thence south through valley of Lake Quinsigamond.

2. Drainage from southeast slopes of Mount Wachusett by way of

East Wachusett, Governor and Trout brooks, thence by way of Quinapoxet River, Chaffin and North ponds. Gap at elevation 700±.

3. Drainage from south and southwest slopes of Mount Wachusett by way of South Wachusett and Cobb brooks, Quinapoxet River, Maple Spring Pond, Eagleville Pond, and Tatnuck Brook. Gap at elevation 800±.

4. Ware River, from west slope of Mount Wachusett by way of Longmeadow Brook, Long Pond, Browning Pond, and Seven Mile River. Gap at elevation 900±.

5. Burnshirt and Ware Rivers, by way of Muddy Pond and Brooks Pond. Gap at elevation 700±.

6. East Branch of Swift River, through Muddy Brook valley. Gap at elevation 600±.

Of these possible courses the only ones to enter into very close examination were the Ware River, by way of Muddy Pond, and the East Branch of Swift River, by way of Muddy Brook Valley. The ancient Stillwater River was given attention through its important tributary, the Quinapoxet River. All other courses were eliminated because their detected water gaps brought the ancient channels at such high elevations along the tunnel line as to make it unlikely that there was not more than enough rock cover above the tunnel.

RELATION OF TOPOGRAPHY TO PLACEMENT OF BORINGS

As the mantle of unconsolidated deposits is of glacial origin, it was found to be of advantage to lay off a narrow strip along the tunnel line marking the areas covered by the ground moraine of unmodified glacial drift deposits, and the areas of the deeper modified and unmodified glacial drift deposits. The relative amounts of each can be seen on the accompanying map, which is an adaptation of that accompanying the United States Geological Survey, Bulletin 760–B, entitled "The Physical Features of Central Massachusetts," by W. C. Alden. Although this map was made from a pure scientific viewpoint, the speaker has found it of inestimable value in checking up on his own studies. The establishment of the boundaries of these two main divisions gave directly an insight into the relative depths of bedrock along the line. The ground moraine, which is indicative of shallow cover (in this section from 0–25 feet), is recognized by the generally unsorted condition of its constituent parts, — heterogeneously mixed rock flour, sand, gravel and boulders. As a general rule, the contours of the ground moraine conform quite closely to those of the underlying bedrock. This unmodified drift is generally thin upon the crests and slopes of the ridges, and in general, all bedrock exposures occur in the areas covered by these deposits. This drift material was deposited by the ice sheet on its retreat, and left in places of higher elevation than the major valleys, which controlled the accumulated run-off of water from the melting ice. The ground moraine, as a result, is comparatively free from water deposition.

In the major valleys, however, the glacial modified drift is found to have been deposited to an unknown depth under the action of water. This is especially true where there was no natural outlet for drainage, or where the outlet had been blocked by the accumulation of glacial drift. These valleys were then transformed into temporary glacial lakes which received the drift materials brought down by the rivers. On the sides and in the bottoms of some of these valleys occur irregularities in the general surface in the form of gravel and sand ridges and terraces. These kame deposits, especially the kame terraces, were probably formed by deposition, along the side of the retreating ice lobe, and the particular one in the vicinity of the west portal had an important bearing on its location.

During the retreat of the ice sheet there were stages of temporary halt, where the ice front remained practically stationary within a narrow zone for a comparatively long period of time. In these zones the material freed from the melting ice was dumped in an irregular manner directly in front of the ice sheet. The topography resulting is similar to that of a terminal moraine topography, in that it is irregular, undulatory, and made up largely of kame ridges, kettle holes and irregular hollows. The material is usually a mixture of rock flour, sand, gravel and boulders, and is part water laid, but is more often not water laid. It is quite obvious when studying this topography in the field that it bears no relation to the bedrock topography, and consequently the depth to bedrock is unknown.

The proper placement of borings in the field was greatly facilitated by the determination of these boundaries of the ground moraine and the areas of the deeper glacial fill in the vicinity of the tunnel line. The latter areas were the critical ones, as the depth of deposition was not known, and consequently these areas were the ones explored with the drill. In the areas covered by the ground moraine bedrock exposures are more numerous, and these were used in studying the bedrock conditions, but great care was necessary in ascertaining that these exposures were bedrock and not large boulders. It is not unusual to find boulders partially buried in the drift, which have been rafted down or deposited by the ice, ranging in size from 5 to 30 feet in their longest dimension. Under these conditions it was often impossible to be positive that an exposure of rock was bedrock. The only criterion, then, to go by was the position of the exposure in place, the similarity in its character to known rock exposures, and the general orientation of its structure with that of the area.

SOME CONSIDERATIONS AFFECTING THE ALIGNMENT OF THE TUNNEL

The location of the intake portal was fixed by the local topography at a point near Quabbin Lake.

The location of Shaft 8, the intake of the Ware River diversion, was fixed by law within certain limits, and by natural conditions along the river bank. Shaft 1, the outlet, was limited to a location on the northwest side of the Wachusett Reservoir, suitable for possible power developments. Because of the possibility of developing a considerable head between the Quinapoxet River–Trout Brook junction and Shaft 1, the location of Shaft 2 was fixed near this former point, where the combined flows of the Quinapoxet River and Trout Brook could easily be diverted into the shaft. These shaft locations established a preliminary line for the tunnel.

INFORMATION FROM BORINGS

Of the 25 miles of tunnel, approximately 15 miles are covered with the ground moraine of shallow unmodified drift, and the remaining 10 miles with the deeper modified and unmodified glacial drift. At no point along the line, except at shaft sites, was it necessary to drill any holes in the former areas. This is primarily due to the fact that the ground moraine, except in one instance, is confined to those areas where the range in elevation is between 700 and 1,250 feet, and also to the fact that all possible pre-glacial drainage courses have their gaps at such high elevations as to assure ample rock cover. In the one exception, the section lying between the portal and Muddy Brook Valley, numerous exposures of bedrock indicated a very shallow earth cover. Of the 10 miles of the deeper modified and unmodified glacial drift, approximately 2.5 miles are above elevation 700. All drilling was confined to the portions of these areas below this elevation, except for shaft site locations.

Fig. 2 shows Quinapoxet Valley. Between Shafts 1 and 2, the tunnel line parallels the course of the Quinapoxet River, which, before the construction of the Wachusett Reservoir, was a tributary of the Nashua River. The course of the river is confined in the area designated as composed of the deeper modified and unmodified glacial drift of Glacial Lake, Nashua. The narrowest part of the present valley is in the vicinity of Malden Hill, where the distance between the ground moraine on either

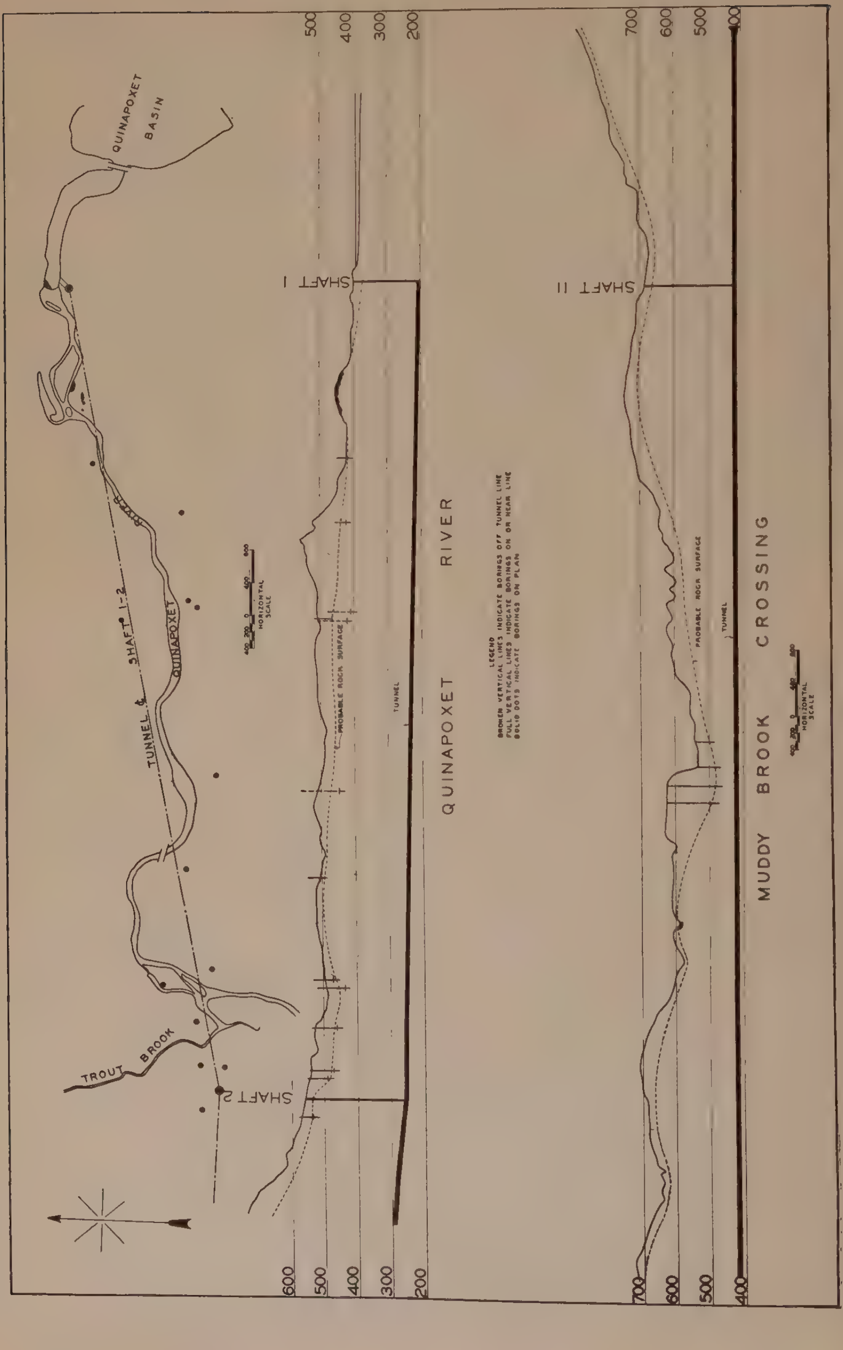

FIG. 2.—PLAN AND PROFILE OF QUINAPOXET RIVER

side is approximately one mile. A valley of this size and depth must have been formed in pre-glacial times, as the present course of the river is wholly through deep glacial deposits. Rock exposures were found at only three locations in the river bed, which indicated that the present river was not flowing over its old channel, and that the pre-glacial channel was lower in elevation.

The late Professor Crosby* has stated that the Quinapoxet and Stillwater rivers, in pre-glacial times, were separate river systems, and that by the more powerful backward erosion of the Nashua River these two systems were captured and became tributaries of the latter. The record of borings for the north dike of the Wachusett Reservoir, near Clinton, determined low rock in the pre-glacial gorge of the Nashua River at approximately elevation 95. Projecting the gorge up the valley to its probable junction with Quinapoxet and Stillwater channels, it was estimated that the low rock at this point would probably be around elevation 320. The lowest elevation of rock near this point, as determined from borings, is at the location for Shaft 1, where rock was found at elevation 373; and from further studies in the field it is quite probable that this rock is within the pre-glacial channel of the Quinapoxet River. It was evident from the start that between Shafts 1 and 2 rock would not be found high enough to assure a continuous rock tunnel. However, other holes were drilled, but showed only a slight rise in the underlying rock, the holes varying in rock elevation according to whether they were within or without the old channel of the Quinapoxet River. The depth to bedrock was also variable, the shallowest earth cover being 32 feet and the deepest 114 feet. As the drift in this area has been eroded to a great depth, it is quite probable that the original drift was deposited to a depth of 175 feet or more. As a result of finding low rock for a distance of at least 1.5 miles on this line, the tunnel was depressed, so as to assure sufficient rock cover.

From Shaft 2 west to Shaft 8 all holes, except in two instances, were placed to establish the location of shaft sites. From Shaft 2 the surface of the ground, and consequently the rock, rises continuously until a maximum elevation of 1,260 feet is reached on Rice Hill in Rutland. This topographic feature marks the divide between the Wachusett and the Ware River watersheds. Several holes were necessary in the location of Shaft 3, as the drift is deposited to a rather great depth, the range in earth cover being from 38 to 130 feet or more. The deep drift deposits in the vicinity of this shaft originated from a temporary halt in the retreat of the ice sheet, which formed a morainal topography, previously described. Shafts 4, 5, 6, 7, 9, 10 and 11 are located either within or close to the areas designated as covered by the ground moraine, and consequently the depth of overlying material at these seven shafts is shallow, ranging from 17 to 25 feet.

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* "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods." W. O. Crosby, Technology Quarterly, Vol. XII, November 4, 1899.

A straight line between Shaft 8 and the south or the north portal locations traverses the Ware River Valley for a distance of three miles. Two other rather large valleys enter this valley from the north, namely, the one now occupied by the Prince River, and the smaller one farther east. All three of these valleys contain the deeper glacial drift deposits, and consequently had an important bearing in drilling operations. From the 700-foot contour on the west side of the Prince River to Muddy Brook Valley the topography is controlled by bedrock, and the surface is covered with the ground moraine. One exception to this is the valley of Moose Brook, but due to the fact that the ground elevation is so high, and also to the fact that the deeper drift peters out approximately three-quarters of a mile south of the tunnel line, this valley was of little importance in drilling operations. The very wide extent of Muddy Brook Valley, its general low surface elevation, and the occurrence within it of the deeper unmodified and modified glacial drift, made it necessary to explore this valley quite extensively.

Ware River and Prince River Valleys

The direction of flow of the Ware River, north of Coldbrook, is parallel to the geologic structure, which is north-south, but at Coldbrook it changes abruptly, flowing towards the west, which is directly across the geologic structure. The distribution of the glacial drift in this vicinity indicated that a former course of the Ware River might have extended in a more southeasterly direction through the deep drift deposits in the vicinity of the Boston & Maine Railroad. A boring was placed in the most likely position to locate such an old abandoned gorge, but located rock at such a high elevation as to discredit any possibility of a gorge existing near tunnel grade.

A series of seven holes across the Ware River Valley, on the site of the diversion dam at Shaft 8, located the lowest rock in the pre-glacial channel of the Ware River at elevation 607, which is approximately 40 feet lower than the flow line of the present stream. At this point the Ware River Valley on the south and southeast is choked quite extensively with the deeper glacial drift deposits, but the present stream has been able to erode a wide and deep valley. A map and field study of the Prince River Valley and smaller valley to the east suggested an origin other than one wholly through river erosion. The drainage area of the Prince River is comparatively small, even when discounting the possibility of glacial drift making its pre-glacial drainage area smaller, and it is unlikely that its run-off could have alone formed this valley. The long axes of the two valleys is approximately parallel to the geologic structure, and also to the direction of glaciation. It is this latter factor supplemented by the first which seemed to favor the origin of these valleys having been through glacial scour of a deeply disintegrated mica schist. The several preliminary borings placed near the junction of the Ware and Prince rivers showed a progressively deeper fill towards the south, with corresponding lower rock elevations. One boring in particular penetrated 161 feet of fine sand, clay and boulders before locating rock at elevation 434. There is every reason to suspect that farther south rock is even lower in elevation, with a depth of glacial drift approximating 250 feet. If this low rock was confined to the pre-glacial Ware River it must have had an abnormal gradient, — a drop of at least 200 feet in 16,000, — which did not appear to be likely. Assuming, however, that it had, other holes were placed farther east on the line to determine at what point and at what elevation the gorge crossed the tunnel line. These holes, although only few in number, indicated that the low rock was confined to the Prince River Valley. As it was advantageous to have the tunnel cross under the Prince River Valley as far north as possible, which is the direction of higher rock, the line was changed so as to be aligned on the north side of the Ware River Valley, and thus cross the Prince River Valley approximately 3,400 feet north of the area known to be of low rock elevation. The profile developed from borings on this line showed that the rock floor of the Prince River Valley was buried to a considerable depth (maximum depth 110 feet), and that the smaller valley to the east was shallow in drift cover.

These facts indicate that the Ware River Valley was overdeepened some 70 to 90 feet by glacial scouring. This indication is further substantiated by the following reasoning. The west wall of the Prince River Valley is composed of vertical beds of hard quartzite, and the east wall of a rather hard granite gneiss, while the intervening valley floor is composed of a soft injection mica schist. The strong rock structure of the quartzite is probably reflected in the schist, except that where the quartzite has yielded to folding without any appreciable fracturing the schist must have been considerably broken and crushed with the occurrence of numerous intersecting joints and possibly faulting. These conditions favored the scouring ability of the ice sheet by abrasive action and plucking. As the ice sheet could not scour laterally because of the hard rock side ridges its only course was to scour in depth.

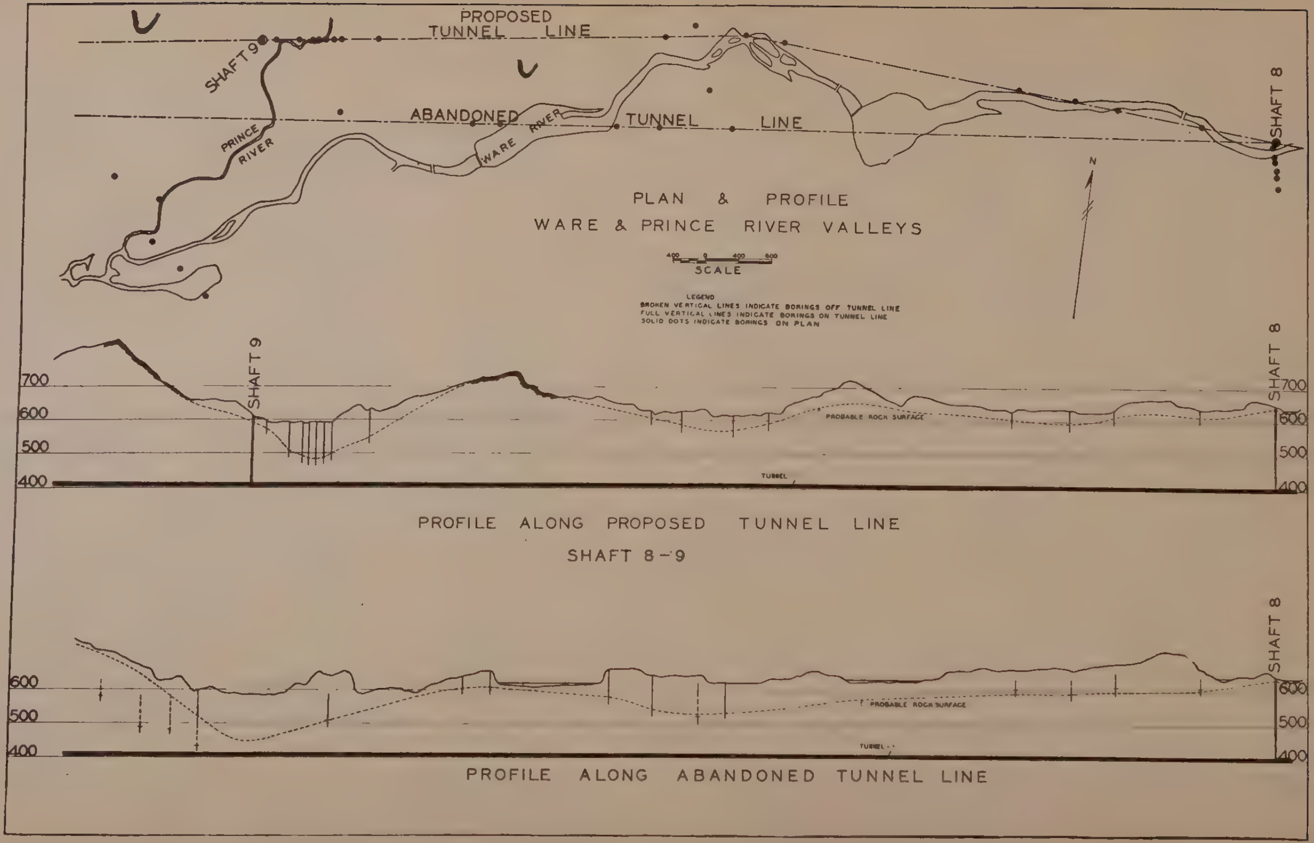
PROPOSED TUNNEL LINE
SHAFT 9
ABANDONED TUNNEL LINE
PRINCE RIVER
WARE RIVER
SHAFT 8
N
PLAN & PROFILE
WARE & PRINCE RIVER VALLEYS
400 0 400 800
SCALE
LEGEND
BROKEN VERTICAL LINES INDICATE BORINGS OFF TUNNEL LINE
FULL VERTICAL LINES INDICATE BORINGS ON TUNNEL LINE
SOLID DOTS INDICATE BORINGS ON PLAN
700
600
500
400
PROBABLE ROCK SURFACE
TUNNEL
PROFILE ALONG PROPOSED TUNNEL LINE
SHAFT 8-9
PROFILE ALONG ABANDONED TUNNEL LINE

FIG. 3. — PLAN AND PROFILES OF WARE AND PRINCE RIVER VALLEYS

Muddy Brook Crossing

The only break in the distribution of the ground moraine west of Prince River is in the valley of Muddy Brook, an impressive physical feature when seen from the higher ground on either side. The valley floor at the present time is irregularly covered for a distance of almost a mile with the deeper modified and unmodified glacial drift. A study of the series of borings on the south and north lines, supplemented by a map and field study, indicated that it must have carried considerable drainage southward from what is now a portion of the Swift River drainage area. The present water parting or blocking of the valley was accomplished by the accumulation of glacial drift in the vicinity of the north line crossing. The nature of the rock floor is dissimilar to that in the Ware and Prince River valleys. In Muddy Brook Valley the rock is chiefly a hard granite gneiss and grano-diorite. Pre-glacial river erosion is perhaps mostly responsible for the formation of this topographic feature. What effect glaciation has had upon it is hard to say, but it is quite certain that some of the irregularities on the rock floor and side ridges were smoothed off, so that some local widening and overdeepening was accomplished.

Summary

From the data obtained from the exploratory work on the Wachusett–Swift Tunnel the speaker submits the following points of consideration which may be helpful to engineers in any future work of this nature:

1. It was found of advantage, in obtaining as complete information as possible, to divide the surface topography into two main divisions, — the ground moraine, of shallow depth, composed of the unmodified glacial drift deposits, and the deeper modified and unmodified glacial drift deposits. In a great many cases the latter occupy valleys formed by pre-glacial river erosion, and in some cases glacial erosion, and consequently the depth of deposition is unknown.

2. The abrasive and plucking action of the ice sheet must be taken into consideration, especially in the softer rock zones, and more especially in valleys floored by relatively soft rock but flanked by hard rock. This fact must be taken into consideration when studying rock profiles, as the tracing of the floor along one line will not always be at the same levels, even 25 feet away. Some considerations affecting this abrasive and plucking action are the local direction of glaciation, the geologic structure, and the orientation of the valleys with respect to glaciation.

3. The rearrangement of drainage is the common rather than the uncommon thing, and attempts should be made to trace out the preglacial drainage courses as far as they might affect the nature of the work.

DIAMOND DRILL BORINGS FOR THE SWIFT RIVER DAMS

By N. LeRoy Hammond,* Member, Boston Society of Civil Engineers

The most favorable dam sites for the creation of a reservoir in the Swift River Valley were examined with the aid of borings by the Joint Board which reported to the General Court in 1922. The investigations at that time were sufficiently broad to confine the selection of sites for the necessary dam and dike to relatively small areas. These investigations showed that bedrock lay at a considerable distance below the natural surface, and that prior to construction it would be necessary not only to develop the actual bedrock profile, but also to have accurate knowledge as to the character of the overburden.

During the latter part of 1926, the Metropolitan District Water Supply Commission entered into a contract with Sprague & Henwood, Inc., of Scranton, Pennsylvania, for the making of borings at possible dam and dike sites. The contract called for four items of work, viz.:

1. Wash borings.
2. Core borings to the surface of sound bedrock.
3. Core borings in sound bedrock.
4. Casings ordered left in place.

The unit price for the first three items was the same for each classification of work, being $4.35 per linear foot. Core borings require that the driving be done in such a manner as to insure the ability to drill through boulders and into bedrock, while wash borings carry only to resistance in the form of large boulders or ledge. As the earlier investigations had indicated the presence of numerous sizable boulders in the material overlying the bedrock, it was deemed necessary to confine all borings to core borings, with the intention of actually entering bedrock, and no wash borings, as such, were taken.

For core borings to the surface of sound bedrock and in rock some of the provisions of the specifications were as follows:

> Where the character of the material will permit, it is desirable to drive not over 5 feet before each washing, and under no circumstances may the wash pipe advance more than 6 inches below the bottom of the casing.

---

* Division Engineer, Metropolitan District Water Supply Commission.

> The contractor shall provide all facilities and assistance necessary to secure samples of material penetrated whenever required as prescribed. Dry samples obtained by forcing the sample tube below the limits of the washing will, in general, be required every 5 feet in depth, and may be required at more frequent intervals.
>
> Unless otherwise ordered, core borings which have been carried to sound bedrock shall be further continued into the rock to such depths as may be deemed advisable by the engineer, usually about 20 feet. Unless otherwise permitted, the recovered core shall have net diameters of not less than 1 inch if diamond drills are used, and not less than 2 inches if shot drills are used.
>
> If the character of the rock to be drilled is such that casing is required to safely drill the hole to the required depth, the contractor shall continue to drive casing to such depth as may be required. The diameter of the casing used shall not be reduced without permission below that which will give the prescribed minimum size of core.
>
> Samples of the material penetrated, other than cores of rock, shall be taken in the manner, and as frequently, as directed, placed in receptacles furnished by the Commission, which shall be so numbered and marked as to be readily identified. . . . The cores of rock shall be carefully handled so that they will not be destroyed or injured. . . . Should it prove impracticable at any depth to obtain a core, or should a seam be encountered, particular care shall be taken to get accurate samples of the materials penetrated, and the correct limits between which no core can be obtained.

The specifications permitted the use of shot drills, but actually only diamond drills were used. Great care was exercised in the operation of the diamond drills, and the diamond loss was kept very low, due in part to the fact that drilling with the diamond bit through boulders was stopped immediately upon penetration through the boulder, and no drilling with the bit in sand was permitted by the contractor's superintendent.

In the vicinity of the proposed dike in the valley of Beaver Brook 26 holes were driven, while at the dam site on the Swift River 32 holes were driven. To develop a cross-sectional profile of bedrock in each of the valleys holes were spaced at intervals of about 200 feet, and somewhat closer as the profile developed possible location of a rock gorge, if any existed. The borings indicated that no gorge exists, and the rock floor is somewhat dish-shaped with out-cropping ledge on the side hill shoulders. The valleys have been glaciated, and most of the irregularities probably have been smoothed out by the erosive action of glacial ice.

Holes were placed longitudinally along the axes of the valleys to determine the probable slope of the rock floor, and to make certain as to the economical location of the position of the structures to be built. For the dike, the relative position of the bedrock to the natural surface ndicates the economical location, while other factors, such as spillway and stream control, enter into an economical location of the dam.

The drilling covered a total of 5,050.8 feet above bedrock and 1,129.85 feet in bedrock at a cost under the contract of $26,885.83. The maximum depth drilled to bedrock below the natural surface was 164.58 feet, this being from a plateau at some distance from the site selected for the dike. As may be expected in valleys with deep glacial erosion, the surface undulations were found to have no direct relation to the cross-sectional profile of the bedrock. The average depth of all holes above bedrock was 87 feet. As a rule, it was required that the contractor drill 20 feet into the rock bottom to make certain that solid rock had actually been entered. In one instance a penetration of about 32 feet was required in order to make certain as to the exact character of the rock encountered, a small percentage of core having been recovered. The average percentage of core recovered from all holes was 67.4, with a maximum of 99.7 per cent. Veins of mica schist yielded but a small percentage of core; however, wash water samples gave evidence as to the character of the rock.

The bedrock was found to be crystalline rock consisting of hornblendic gneiss and granite gneiss, with gradations between, at the dike site, and hornblende diorite, quartz mica schist and granite gneiss at the dam site. The rock is sound and shows no signs of being badly broken or decayed, and is of a type which is not easily attacked by water or yields in any way to abnormal conditions caused by the building of the structures.

As it was early thought probable that it would be necessary in the construction of both the dam and the dike to excavate the overburden to sound bedrock, and as this rock lay over 125 feet below the natural surface, extreme care was exercised in the securing of samples in the overburden. At the dike site, in particular, all gradations of sand were encountered from fine silty sands to coarse sands and gravels, with occasional nests of boulders at varying depths. All material was found to be extremely porous. As a whole, the material is substantial and will support such structures as are contemplated. It is highly pervious to water, and it will be found necessary to carry an impervious core to the rock floors of the valleys.

Because of the nature of the overburden, the successful driving of all holes was extremely difficult, but to the credit of the contractor, it may be said, all holes once well started were completed and none were abandoned. One of the most difficult holes required twenty-two days of actual drilling before successful completion, with an average rate of 6.1 feet per day. In many cases holes were started with a 4-inch casing reducing to 2½-inch casing when necessary. All machinery was gasoline-driven, and six complete drilling rigs were in operation as the work advanced. Water was provided by gasoline-driven pumps and pipe lines to the drilling rigs as necessary. The customary rigs utilized for this type of drilling were employed, the casing being driven by the gravity fall of a hammer guided on a length of 2½-inch pipe coupled to the driven casing, the blow being taken on a coupling at the head of this casing. The casing was driven 5 feet, if possible, before washing, but as depth was increased it was found necessary to wash with the driving.

Many nests of boulders were encountered in the drilling ranging from small rounded stones which could be driven aside to large boulders which required drilling and blasting. If boulders could not be driven to one side or broken up by a charge of dynamite, they were drilled with the diamond bit and blown by dynamite. In the use of dynamite, the casings were pulled about three feet before blasting, in order to protect the bottom of the casing from being bent or blown off. In many cases it was found that the sand overlying a boulder was so fine and so saturated with water that before it was possible to lower the dynamite the sand had flowed back into the casing as much as 15 feet. This difficulty was successfully overcome by washing the dynamite to the boulder.

Before drilling with the diamond bit the casing was firmly seated on the bedrock by driving and blasting if found necessary, in order that sand be kept from the bit. The diamond bit consisted of a soft steel blank with a hole slightly over one inch in diameter in the center, through which the sample core of rock was fed. On the circumference of this hole four black diamonds are set into the steel protruding slightly below the blank as a cutting edge. Likewise, on the outside of the blank, four more diamonds are placed forming an outer cutting edge. The core barrel, which is about three feet long, and on the end of which is placed the bit, is attached by a string of rods to the drilling machine at the surface, which rotates the rods and slowly feeds them downward as the cutting progresses.

As a rule, dry samples were taken about every 5 feet, the wash water being carefully watched for indications of a change in material. It was observed that wash samples, as a rule, were somewhat finer than the dry sample of the actual stratum in place, and could not be depended upon to do more than indicate about what the material might be. The taking of dry samples, due to the necessity of pulling a string of wash rods, involves considerable time, but the results are far more dependable than those obtained from wash water, and for explorations of this character should be the type of sample secured. The contractor was equipped with several types of sampling spoons for the taking of dry samples, and many times it became necessary to try them all before a dry sample could be secured. For fine sands a cylinder with its end closed, and with slots cut in the side above a pocket for the sample, proved efficient in many cases. Our experience on this work has shown that with perseverance dry samples are possible to obtain.

A log of the driving was carefully kept of each hole, and samples placed in standard sample bottles were labeled with all necessary information as to their exact location. Rock cores were placed in flat boxes with channels of a width slightly larger than the core, and were placed in the order in which taken from the core barrel; elevations at which taken being marked on the partitions separating the box channels, and wooden separators being placed between each set of cores from the core barrel. Such an arrangement shows the geologist exactly the condition of the rock encountered, and facilitates an analysis of the geologic conditions.

While no work of excavation has as yet been undertaken on the structures to prove the accuracy of the work of exploration, yet the methods followed in the actual drilling and keeping of records give an excellent basis for the design and methods to be followed in the erection of the structures.

PRELIMINARY INVESTIGATIONS FOR THE SCITUATE TUNNEL OF THE PROVIDENGE WATER SUPPLY

By Richard R. Bradbury *

The westerly portion of the Scituate Aqueduct, that carries water from the new Scituate Reservoir to Providence, Rhode Island, is in tunnel. This tunnel is about 3⅓ miles long, of horseshoe shape, 7 feet high and 7½ feet wide inside the lining, and is in hard rock for its entire length.

The approaches at the two ends were made in open cut until a sufficient cover of rock was obtained, and the portions of the tunnel adjacent to the portals were made circular, 7½ feet in diameter, and grouted in order to make them watertight.

The locations of the two portals were selected and a tentative line run on the ground straight between them. The total cover, earth and rock together, is not very great; the maximum is about 225 feet and the average not over 140 feet. For about 2,500 feet east from the west portal there are a number of ledge outcrops near the tunnel line, so it was not considered necessary to investigate this portion further; but after this

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* Division Engineer, Metropolitan District Water Supply Commission.

first 2,500 feet there was only one other outcrop in the whole distance to the east portal.

After the two portal sites had been investigated, therefore, borings were begun about 1,500 feet east of the most easterly outcrop. These borings developed that the rock surface was below tunnel grade. Enough borings were made to make it appear probable that this low place was not of great extent, either longitudinally or transversely of the tunnel line, and that it was not a buried rock gorge, but rather a glacial rock basin. The tunnel line was therefore moved about half a mile north and further borings made, which indicated that on this new line there would probably be a safe cover of rock. Seven borings were put down on the first line in a distance of about 1,900 feet, and six on the second line in a distance of about 1,100 feet, which developed two cross sections of the rock surface across the basin and up on either side.

The locations of the portals were not changed, so that the new line departed gradually from the first one and then gradually returned toward it again. No further borings were made west of the basin, as the rock outcrop gave sufficient indication in that direction of a good rock cover, but eastwardly they were put down, on or near the new line, at intervals of about 900 feet all the way to the east portal. No further depressions developed from these borings; the greatest depth to rock in any of them was about 55 feet, with a rock cover of about 140 feet above the tunnel roof. It was therefore felt that it was safe to accept this second line as the location for the tunnel.

These borings indicated that for nearly the entire length of the tunnel the rock would be a very hard gneissoid granite, and that the east portal and about 500 or 600 feet of tunnel at the east end would be schist.

The borings gave a very good indication of the conditions actually encountered while excavating the tunnel. About all that they did not show were two soft stretches in the west tunnel, which were both short and not serious, and a succession of narrow dikes of trap rock and of seams or fissures where the granite had apparently cracked open and the fine white sand of the overlying subsoil worked down in. We were constantly encountering one or the other of these during excavation.

Of the sand seams, one was about six feet across, one a little over two feet, and the rest only about a foot or so. Only the two largest of these seams required timbering.

The largest of the trap dikes was 22 feet across. This was the first one encountered, only a few hundred feet west of the shaft from which most of the work was done. None of the others were more than a few feet across. The edges of these dikes were sharply defined, and the granite next to them was usually discolored and somewhat soft. The only stream of water of any size encountered in the tunnel came from an open seam at the east edge of the 22-foot dike.

There were a number of swamps on the tunnel line, all hard-bottomed and none of them of very great extent. One of these swamps was at the angle where the borings had shown the rock to be deep, and most of the water encountered in driving the tunnel was in the vicinity of this place. There was not a great deal of water, however, even here, and the rock was firm and sound and did not require timbering. The tunnel was not driven directly to the angle, but was carried around it on a two degree curve about 800 feet long in order to get by with the concrete forms. Because of the wetness and the blocky character of the rock, the concrete lining, normally of 3 inches minimum thickness, was increased to 9 inches minimum for several hundred feet around this curve.

The only timbering that amounted to anything was a stretch somewhat over 200 feet long in the schist near the east portal. The granite was, as indicated by the borings, very hard and a good, firm, sound rock. Its hardness was a surprise and disappointment to the contractor, as it slowed down the drilling speed very materially and required a great deal of drill sharpening. It broke very well, however; there was very little overbreakage in the roof, and the sides came out quite close to line, so that in about 12,000 linear feet of tunnel the actual excavation was over 1,300 cubic yards less than the theoretical.

We did not locate the contact between the schist at the east end and the granite exactly. The schist merged gradually into the granite, and we were unable to say just where one stopped and the other started.

It is evident that this preliminary investigation paid for itself many times over. If the tunnel had been built on the line first laid out it would have run out of the rock for a distance of, perhaps, a thousand feet, which would have added very greatly to the expense of construction, besides giving a less stable structure. As it was, over 99 per cent of the horseshoe section was built without timbering, and in 93 per cent the minimum thickness of lining was used. This resulted in very material economies in both excavation and concrete, as well as hastening the time of completion.

ELECTRICAL EXPLORATION METHODS FOR LOCATION OF DAMS AND TUNNELS

By Irving B. Crosby,* Member, Boston Society of Civil Engineers

There are many different ways in which the geologist can aid in planning and carrying out a large engineering undertaking. Some of these are: locating bedrock where it is not exposed; learning the nature of the overburden; and studying the character of the rock to determine whether it is suitable to serve as the foundation of a large structure, whether it contains cavities or is soluble in water or has faults or other weaknesses. In working out these problems the geologist should not confine himself to the immediate locality he is to study, but will get better results, and in the end save time, if he obtains a thorough understanding of the geology of the adjacent country before attacking the local problem. From a general geological study of the locality it is often possible to obtain an approximate idea of the shape of the bedrock surface, even though it may be deeply buried, and this makes it possible to guide a campaign of electrical prospecting and drilling so that it will give the maximum information at the minimum of time and expense. In fact, one of the most useful spheres for geological aid on an engineering problem is in the supervision of subsurface explorations, whether by test pits, drilling or electrical prospecting. By understanding the origin and nature of the deposits which are being investigated, the geologist can then more intelligently forecast the conditions between and beyond the known points, and thus get the desired information from a comparatively few test pits or drill holes.

In at least one of these problems, that is, in locating bedrock where it is deeply buried, electrical prospecting can be a valuable tool for the geologist, and if it is properly handled with an understanding of its possibilities and limitations, time and money can be saved and information obtained much more quickly than by other means.

Formerly the only way to learn about conditions below the surface was to drill or dig a test pit or shaft, which is often slow and very expensive. Last spring, while studying the geology and supervising the drilling campaign at the Fifteen Mile Falls development of the New England Power Association, on the Connecticut River, the need of some faster and less expensive means than drilling was felt, and the different types of geophysical prospecting were investigated, with the result that the surface potential electrical method, as applied by the Schlumberger Electrical Prospecting Methods of New York, was chosen.

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There are six types of geophysical prospecting, and a brief résumé of these may be of interest. The gravity method depends upon variations in the force of gravity, which are determined by the Eötvös Torsion Balance. It is probable that this could be used to determine depth to bedrock under favorable conditions, but the apparatus is complicated and delicate. In the seismic method an artificial earthquake is produced by exploding a charge of dynamite buried in the ground. The vibrations are recorded on seismographs placed at various points in the area to be studied, and from these records the exponents of this method claim to be able to determine the depth to rock. The fact that a hole 20 feet deep must be bored for the dynamite would be a serious drawback in the bouldery soil of much of New England. Also the apparatus is cumbersome for use in rough country such as we frequently have about dam sites. For these and other reasons we did not make use of this method. The magnetic method is used with magnetic ores, but is, of course, not applicable to determining the depth to bedrock. Some metallic ore bodies act as a natural battery and produce an electric current which can be detected by using the proper instruments. The self-potential method is based on these facts, but is of no use in our particular problem. In the inductive method a current is induced in the ground, and it is possible to locate by this means metallic ore bodies, but not bedrock.

There remains the surface potential method. This is based on the fact that different materials in the earth have varying electrical resistivities, and by passing a current through the ground it is possible to study these. The current does not go in a straight line along the surface between the electrodes, but enters the ground in all directions, passing deeply into the earth. Metallic ore bodies are much less resistant than the surrounding rock, and their presence can be detected by studying the electrical field at the surface of the ground. Bedrock usually has a much greater resistivity than the overburden, and thus produces distortions in the electrical field on the surface which can be detected, and from these data the depth to the resistive layers can be calculated.

The current is applied by two electrodes several hundred feet apart, one of these being at the position where the depth to rock is to be determined. Measurements are taken of the drop of potential between two other electrodes which are moved to different points about the position. When used for locating bedrock the success of this method depends upon the difference in electrical resistivity between the rock and the overburden, and fortunately here in New England, where hard, old rocks are common, this difference is usually great.

There is not time here to explain fully the details of the surface potential method, and, indeed, this should be done by one thoroughly familiar with the technique, whereas my part has been the application of the method to practical engineering problems and the solving of geological problems by means of the results obtained by this method. Those who wish to learn more about the determination of depth to rock by electrical prospecting can find further details in Technical Publication No. 131 of the American Institute of Mining and Metallurgical Engineers.

The surface potential method has been used for about fifteen years in prospecting for metallic ore bodies and in studying the structure of oil fields, and several concerns are now successfully engaged in this work. In so far as known, however, electrical prospecting had never before been used for studying the foundation conditions at a dam site.

We thus see that of the six methods of geophysical prospecting, there are three which might be used to determine depth to rock, but of these the surface potential method seems much the most practical, and it has been used for four months on one development and some two hundred determinations of depth to rock have been made by it. Where conditions are favorable, from one to three determinations a day can be made, and the cost varies from $50 to $75 each, according to conditions. Where the rock is not near the surface, this is much cheaper than any other known method of learning the depth to rock, and it has proved successful for depths as great as 200 to 300 feet.

The size and weight of the apparatus used is of great importance when working in rough country. The complete outfit weighs about 300 pounds, and a large part of this is in reels of wire. Where roads exist it can be easily carried in the back of a Ford car, or in very rough country the equipment can be divided into separate packages and loaded into a canoe or packed on the backs of men. The electric current is supplied by a special dry battery of very moderate size, and the instruments fit into a strong, compact carrying case. It is possible to carry it practically anywhere.

Since electrical prospecting had never been applied to this type of problem before, the Schlumberger electrical prospecting methods gave a demonstration at eight drill holes where their results could be checked by the drill records, which they had not seen. This showed that, except where conditions were unusual and could be detected by the geologist, results could be depended upon as being within 10 per cent of the actual fact. These were for depths of 27 to 142 feet, the deeper determinations being the more correct.

Electrical prospecting can be of use to engineers in making a preliminary study when time and expense prohibit extensive drilling. In such cases it may be the only possible means of locating bedrock, and although the results may not be entirely accurate, they will, taken as a whole, give a good understanding of actual conditions from which preliminary estimates for a more detailed study can be made. In these more detailed studies electrical prospecting has its place in connection with the drilling campaign. It may be used to greatly extend information obtained from the drill, and when the electrical results are checked occasionally by the drill records much accurate information is available. I have found in actual practice that the best results are had when the geologist combines the drill information with that obtained by electrical prospecting, and studies them as a whole. Where the electrical results agree with the geological expectations they are probably accurate, but where they disagree seriously they should be checked by the drill. In this way, by co-operation between the geologist, the driller, and the electrical prospector, the maximum amount of information can be obtained at the minimum expense.

An explanation of the geological conditions at Fifteen Mile Falls, where electrical prospecting was first applied to engineering problems, will help in understanding its possibilities. The Connecticut River is here flowing in a narrow valley. There are occasional edges, sometimes on one side and sometimes on the other. Beneath the present river, at depths of from 50 to 100 feet, and winding from side to side, is a buried gorge made before the glacial period. At the close of the ice age the valley was blocked with glacial drift, and the river, seeking the sea, wandered down this drift-filled valley, paying no attention to the buried gorge beneath it. In some places the river is directly over the buried gorge, and in others it is at one side or the other. This accounts for the fact that ledge is found on either side, but never extending completely across the valley, though in one place ledge does exist across the river bed, and the buried gorge is off to one side under thick deposits of clay, sand and boulder clay.

It was necessary to determine the location, depth and width of this buried gorge at both the upper and lower dam sites. Drilling in the glacial drift was very slow and expensive on account of the numerous boulders. By means of electrical prospecting we studied this buried gorge for a considerable distance above and below each of the dam sites. This information enabled the engineers to make certain the dams were located n the most favorable places. At the immediate sites a drill was used to et further information about the depth to rock, and to obtain samples of he overburden which filled the buried gorge.

At the upper dam site a diversion tunnel was proposed, and the lectrical method was used to determine the depth to rock along the line f this tunnel, to make certain there was everywhere a sufficient thickness f rock over the tunnel.

The location of ledge below the dam was also studied to determine hether it was feasible to excavate a long tailrace. Many electrical eterminations of the depth to rock were made on the river bank and on gravel bar and island, and in critical places a drill was used. This ethod was also used in a proposed borrow pit area to learn the depth to ock.

It was a pleasant surprise to learn that some information could be btained about the nature of the overburden, due to the fact that clay s much less resistive than sand. Accurate results were not obtained here, ut the indications were useful in making a study of the geology of the lacial deposits.

I have briefly explained the uses of electrical prospecting in one large evelopment, and I will add that it is now being used in a preliminary tudy of several dam sites on the St. Maurice River in Quebec. Here some ubsurface exploration was necessary before winter to allow the comple- ion of the preliminary geological investigation, and obtain sufficient nformation to permit the engineers to study the various possible power evelopments during the coming winter. Under the difficult conditions xisting in the wilderness this information could be obtained by no other eans in time to be of use.

Electrical prospecting is a new and valuable tool for the engineering eologist, and it will help him to solve quickly the problems which the ngineer may bring to him.

Discussion

Mr. Frank E. Winsor:* It requires considerable temerity for an ngineer to attempt to speak in geological terms in the presence of these minent geologists. It may, however, be of interest to briefly outline ome of the fundamental problems of location of the 25-mile tunnel om the Wachusett Reservoir to the proposed Swift River Reservoir, e construction of the easterly portion of which from the Wachusett eservoir to Coldbrook is now under way.

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As you undoubtedly appreciate, it is most important from the standpoint of economy to locate the tunnel in rock, and it is of equal importance to so space the shafts that the tunnel may be completed in time to be available when needed. Shaft sites must be located at required intervals at points where the rock is near enough to the surface so that it can be reached by economical methods of shaft construction. In order that the tunnel may be available to bring the spring flows of 1931 from the Ware River into the Wachusett Reservoir, it was considered necessary to locate the shafts about 2 miles apart. Shallow earth cover was found, except at Shaft 3, where an open concrete caisson was used to reach the rock at a depth of about 60 feet. The territory through which the tunnel passes is covered quite deeply by glacial drift, and few rock outcrops are to be found. More extensive investigations by borings were therefore necessary than would otherwise have been required in order to reasonably insure adequate rock cover over the tunnel roof at all points.

Another problem was to so locate the easterly end of the tunnel that it could be put under pressure in order to reverse the flow in the west half of the tunnel and cause the Ware River floods to flow westerly into the Swift River Reservoir, and also so that the tunnel could be used as a penstock for a power plant to be erected at Shaft 1 after the completion of the Swift River Reservoir. It was finally decided that it would be best to drop the tunnel into the rock and put it under pressure at all times for about 3½ miles at the easterly end. The power plant will be located in a building at Shaft 1, the shaft and appurtenant structures being designed to take a head in excess of 100 feet.

From the standpoint of economy, the rock so far as revealed is excellent in that it is reasonably sound, it stands up generally in the tunnel without support, the leakage of ground water through it is not too great to be handled by pumps of moderate capacity, and it is generally suitable for concrete aggregates for tunnel lining.

The assistance and advice of the geologist in the location and design of tunnels, dams, etc., is most important. In the preliminary work as well as in the construction, Dr. Charles P. Berkey, Professor of Geology, Columbia University, who was also employed in the preliminary investigations of 1922, is retained.

The division engineers in charge of the tunnel construction keep track of matters of geological interest, Frank E. Fahlquist, assistant engineer, who presented the first paper of the evening, spending such time as is required upon this phase of the work, and keeping in touch with Dr. Berkey, who visits the work from time to time as required.

This tunnel will reveal the rock formations of a 25-mile cross section of central Massachusetts in an unusual way, and it is particularly gratifying to the engineers that the geologists of Boston and vicinity are interested to improve this opportunity for geological research. They may be assured of the co-operation of the engineering and geological staff of the Commission.

It would be of interest to know whether the method of exploration described by Mr. Crosby has been tested out sufficiently to prove the possibility of differentiating between ledge rock and large boulders or groups of boulders. Under the conditions existing in the boulder country through which this tunnel passes, with considerable depth of cover over the rock and with few outcrops, diamond drill borings are obviously dependable, provided that the depth of penetration into the rock is sufficient to eliminate any doubt as to boulders. While the other method is of undoubted value in preliminary investigations, it appears doubtful to the speaker whether it should be depended upon where considerable accuracy is desirable and where much would be at stake in case of error.

Dr. Charles Terzaghi:* It is a rather unusual experience to meet engineers who are seriously interested in the geological phase of their work. For this reason the Society is fortunate in welcoming three of them on a single evening.

The speakers have justly emphasized the practical benefits which can be derived from proper application of engineering geology to engineering problems. Nevertheless, this science is still far away from fully serving its purpose. This becomes manifest in connection with almost every difficult piece of underground work. Thus, when the last railroad line was built across the Austrian Alps, the best geologists of the country were invited to make a careful study of the geological conditions and to present their geological forecast. Nevertheless, some of the tunnels turned out to represent veritable pitfalls, with an extraordinary capacity for swallowing contractors' money. The causes of these shortcomings become manifest, if one peruses the reports which from time to time are published concerning underground operations. If published by engineers they often contain no indications whatsoever concerning the geological conditions in existence at the site. On the other hand, if published by geologists we usually remain uninformed concerning the engineering character of the exposed strata. Very seldom does one find a report in which both the geological and the engineering aspects of the situation are as adequately treated as they are, for instance, in the book of Mr. Lazarus White about the Catskill Aqueduct. As a consequence there is a gap between engineering geology and engineering practice which cannot possibly be closed except by systematically correlating geological and engineering facts. The mere intention to correlate these two sides of the same thing would inevitably direct the attention of the engineers towards geological phenomena, and the attention of the geologists toward the quantitative side of geological facts.

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Suppose, for instance, information is requested concerning the leakage around the wings of a dam, through strata of glacial sand and gravel. At the present state of engineering geology the geologist is satisfied to testify that the deposit is very permeable or feebly permeable. At the very best he supplements his statements by the results of a few primitive permeability tests performed on samples collected more or less at random. No improvement can be expected unless the construction of the dam is followed by careful water measurements performed on measuring weirs, for the purpose of finding out how much water is actually lost, as was, for instance, quite recently done in connection with the Granville storage dam in Massachusetts. If measurements of that type are performed on a great number of dams and conscientiously correlated with the geological findings, the engineer will be far better equipped to take advantage of geological expert testimony.

In brief, what we need is a dictionary for translating qualitative geological statements into quantitative terms. The speakers of this evening are very well equipped to furnish contributions towards such a dictionary in the course of their future professional career, provided they have the good luck to become connected with "rotten jobs."

F. K. MORRIS:* Through the good offices of Professor Voss, and the kindly courtesy of Mr. Winsor and Mr. Peabody, permission was given to some of my colleagues and myself to study three of the tunnels, under Mr. Fahlquist's guidance.

The reasoning which Mr. Fahlquist followed was especially ingenious and sound, and I want to pay tribute to it. In the case of the Prince River, for example, the question whether the buried rock floor would lie at dangerous depth could have been determined by borings, and very probably could have been solved by electrical exploration. But in this case reasoning proved more economical than tests. The preglacial rivers had developed their courses throughout tertiary time, which is estimated at about 30,000,000 years; it was a fair inference that their rock channels would have attained a gently sloping gradient. But the gradient indicated by the borings in the buried channel of the conjoined Prince–Ware

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River is steeper than that of the Yellowstone in its gorge below the fall. Considering the small drainage area and relatively soft rock in the Prince River Basin, Mr. Fahlquist argued that the anomalous gradient was due to local gouging by the ice, and would not extend far upstream. Upon this thread of logic he reposed such confidence that he advised relocating the tunnel, and gained at once time, money and safety for the construction.

If I may add anything to Mr. Fahlquist's excellent account, it would be a brief word about the jointing systems, which, always interesting, are of especial interest in these tunnels.

Most schists are steeply tilted and folded rocks. But here, between the tunnels at Shaft 2 and Shaft 6, the schists lie almost horizontally. The schistose structure is parallel to the true bedding of the rocks, which were originally sediments. We must therefore infer that the rocks, for a distance of over 5 miles, have never been disturbed to any greater degree than we now find them. Horizontal schists are not unknown, but they are uncommon. East of Shaft 2 the beds tilt up, dipping towards the west; at Shaft 7 they tilt up, dipping toward the east. Thus the horizontal rocks have the structure of a syncline, — an exceptionally broad and flat syncline in this region of intensely crumpled rocks.

The most persistent, regular and closely spaced joint system in the formation is parallel to the bedding of the schist. The rocks break in plates ranging from an inch to 2 feet in thickness, with an average of about inches.

There are other joints which cut across the bedding in various directions, and stand at much steeper angles than the bedding joints. They can be reduced to two systems, one set or system striking northeast, the other northwest. The joints do not lie with perfect consistency, but vary on each side of the average direction, intersecting one another. Thus in the northeastward-striking set we find joints whose strike varies from N. 30° E. to N. 56° E.

The joints determine the planes along which the rock can be most readily excavated. The roof of the tunnel at Shafts 2, 4 and 5 is completely bounded by joints. The roof slopes gently down along a bedding-joint and then turns abruptly up along one of the cross-joints, then slopes downward along the bedding to another cross-joint. Thus the roof is a series of "jogs." As the tunnel is cut east and west, its course lies obliquely to the northeast and northwest joint-systems, so that the sides of the tunnel naturally form a series of blunt projections and shallow recesses, both bounded by intersecting cross-joints. In many of the recesses more rock must be removed than the contract requires, while the blunt projections must be broken away, in either case increasing the cost of excavation. But this difficulty is partially balanced by the rock's tendency to spall off in flat, thin plates nearly parallel to the excavation. I think this is due to strain-effects in the rock, induced by movements of the earth's crust, — an ancient, compressive movement which has never been relieved until the excavation of the tunnel substituted air pressure for solid rock.

DR. TERZAGHI: If all dam sites were to be studied with the care and skill with which Mr. Crosby investigated the dam sites on the Connecticut River, the number of dam failures would materially decrease. The idea of using the electrical method of prospecting was very fortunate. Although these methods have not passed beyond the experimental stage in about ten years, their range of application rapidly expands. Quite recently, in Germany, by using similar methods, five fault lines were found to exist within a dam site, and three more within the reservoir area. As a result of these findings the dam site was abandoned. It will be very fascinating to follow the development of this new and startling branch of applied science.

MR. CROSBY:* Mr. Winsor questions whether electrical prospecting would have been sufficiently accurate to use along the Wachusett–Swift Tunnel line.

I believe it would have been very satisfactory there. There would have been cases, of course, where checking with the drill was desirable, but even if there were occasional results that needed checking, there would still have been a great many cases where results were certain, and thus much drilling could have been eliminated. Take, for instance, a case where it was necessary to be certain that bedrock was not deeper than 100 feet, and the electrical method showed it to be 50 feet down. The factor of safety here is sufficiently large so that there would be no need to check up by drilling, but if, on the other hand, the electrical indications were that rock was 95 feet down, I think checking with the drill would be needed to make certain that it was not deeper than desired. But even if the electrical method were used very conservatively, and checked with the drill wherever there were any doubts, it would greatly cut down the amount of drilling. Errors due to large boulders are not to be feared where the rock is deep, but only where the rock is near the surface. In two cases at Fifteen Mile Falls, where the electrical determinations were in considerable error, it was apparent from a study of the geology that they were not correct, and they were therefore checked by drilling. I do not think any serious error is likely to get by if the geology is well known. I will say in general that in locating a tunnel line like this electrical prospecting would be of great assistance to both the geologist and the engineer.

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* Consulting Geologist, 6 Beacon Street, Boston.

QUESTION: Would you advocate using it for a preliminary investigation for the purpose of determining where you could more economically use your money for borings?

MR. CROSBY: I think that is one of the places where this electrical method is most valuable, and where there is a very great field for it, because you can soon find out where you need borings, and also learn where you do not need them at all. The work can also be done very quickly, as one operator with two or three unskilled assistants can make two or three determinations during the day, and give the results the same evening. To be sure, the results are sent to the New York office for checking, but any change they might make would be slight. There is no other method known for getting subsurface information so quickly.

MR. ALFRED C. LANE:* The mining engineers have authorized the publication of a book, including not only Mr. Crosby's paper but also a number of papers on these geological methods. I have just finished writng up the biography of Crosby, Senior. I am not going to call this Mr. Crosby a "chip of the old block," because he is too big, but I want to just remind you of the work that he and Mr. Freeman did together, and I want to call attention to the importance of the geologist and the engineer working at the same time.

Years ago I met on the train one of the contractors on the Catskill project. It was on the sleeper, and he told me, I remember, how they pent $100,000 in geological studies before they did any drilling. Berkey and Kemp were two of the men employed. This is not said in any criticism of Mr. Berkey. He is secretary and I am vice-president of the Geological Society. But it is a fact that he cannot be watching this tunnel all the time because he is on the Boulder Dam. I think Massachusetts hould take advantage of the offered assistance from her local geologists who were able to stay on the ground all the time. I'd like to know what he terms mean — what "mixed rock" actually means. I'd like to have amples go to some laboratory like that of Dr. Terzaghi's at Techology. The only way is to have some local geologist go through fairly ften. There may be traps and seams of sand which may let water in, nd also may let water out if the water is under pressure, and even though ou have it nicely coated with 3 inches of cement, if that is going to spall f there may be a chance for the water to leak out. I maintain that the geologist and the engineer should work in close contact and understand each other's terms.

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* Geological Prospecting Committee, American Institute of Mining Engineers.

MR. WALTER C. VOSS:* I know practically nothing about the geology of this tunnel or about its engineering, but I was fortunate in being present on several inspection trips, arranged through the courtesy of Mr. Winsor and Mr. Fahlquist. My first visit showed me how a young college graduate who had majored in geology, and, with some experience on outside work, used good sense in applying pure science to tunnels, with the result of an actual saving in dollars and cents to the public. On one of the other trips, several of the most eminent geologists in this part of the country proposed frequent trips to the work in order to cover details of geological data. I would suggest that such frequent inspections would be desirable, and that all such data should be reported, at least as an appendix to the reports of the Commission.

PROF. J. W. HOWE:† I hesitate to rise in this gathering because I am from the backwoods of Worcester, and I feel rather lonesome because I doubt if any Worcester engineers are present. The Worcester engineers mostly participated in the Hoover parade.

Seeing Mr. Voss on the floor naturally brings up the subject of concrete. Since we have under discussion applications of geology to engineering problems it occurs to me that it might be interesting to mention one such application which certainly has not up to the present time been worked out, and which may not have a very important bearing but interested me a year or two ago. This is in connection with locating deposits of sand for concrete.

For economy we prefer well-graded sand with a fineness modulous of 3 to 3.1 or 3.2. Much of the sand we find in Worcester is very much finer. It may run down to 2½ or 2. Then it requires more cement to get the same strength of concrete. I believe there is a very close relation between the occurrence of deposits of sand with respect to grading and the glacial map of the area. There is a glacial map of central Massachusetts, probably also one of the whole State, which maps the location of the terminal moraines, and it is reasonable to suppose that the terminal moraines are composed of material which grades from coarse to finest particles of sand, and investigation seems to bear out that theory. On the other hand, in places which have been the beds of glacial streams, where the sand deposit has been the result of the flow of water, it is quite natural to suppose that the deposit will be highly stratified and rather fine, and investigation has indicated that to be the case.

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* Associate Professor of Building Construction, Massachusetts Institute of Technology.
† Department of Civil Engineering, Worcester Polytechnic Institute.

Now it would be far-fetched to say that this has a very important meaning, but in a country where one is not familiar with the sand and gravel deposits, a study of the glacial map might facilitate the location of proper and economical deposits.

MR. LANE: The Wisconsin Geological Survey had charge of half a million dollars' worth of road work. They always went ahead and picked out the material, discovering just the necessary grade, and notified the contractor, and so secured a saving of about 50 cents per cubic yard, and they figured it was rather higher than Wisconsin iron ore in place.

MR. KENNISON:* I would like to say that the engineering organization of the Commission that is building the tunnel plans and expects to co-operate to the fullest extent practicable in keeping a complete record of the materials encountered; and the best evidence of their intention is that chapter 321 of the Acts of 1927, under which we are operating, makes it mandatory for the Commission to publish in every annual report a complete statement of the geological aspects.

DR. CHARLES P. BERKEY† (by letter): I wish it might have been possible for me to be present at the reading of these papers; then I could have joined in the discussion with a greater feeling of at-homeness. The problems discussed are not strange to me, neither are the men who have presented and discussed them, but the setting and the atmosphere of the meeting, which is the chief excuse for discussion, cannot be reproduced in the galley proof which I have before me and which now must stand for all these more inspiring factors.

I can pay tribute to the excellent presentations, and this I do heartily; I can lend my support to the conclusions reached, and this I do with equal readiness. I can even vouch for the complexity of the different problems and the extreme obscurity of some of the data that were finally used to good purpose.

Perhaps I can be of better present service, however, if I go back to the beginning, to the preliminary steps in the Swift–Wachusett project. First steps always have so many uncertainties. So much of ultimate success depends on taking them in the right direction. I am firmly convinced that many projects make their big mistakes right there. Excellent work is done in later stages, but they get started wrong, and then it takes a giant to help them out.

In this connection I would like to pay a tribute of great respect to Mr. X. H. Goodnough, whose far-sightedness in including geological investigation in the earliest steps of this project measures up to the best up-to-the-minute practice. I recall that he regarded the geological conditions with much concern, and repeatedly asked that these physical elements be checked up and interpreted.

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* Designing Engineer, Metropolitan District Water Supply Commission.

† Geologist, Metropolitan District Water Supply Commission.

It is not any easier for the geologist to be held responsible from the very beginning, but it is certainly much more satisfactory. It puts more independent responsibility on him if he must help select the first trial sites as well as help decide the chief alternatives and the final choice. Those steps have many pitfalls. Generally even the final site is selected on scanty evidence. The more extended exploratory program begins then in earnest, and from that point on the steps are clearer. But if a mistake is made before that stage is reached it cannot be completely overcome. Generally the major points in the early stages are essentially of a geological nature. Too often they are regarded as engineering problems with a troublesome and somewhat irritating and objectionable geological flavor. Men capable enough in their own field of engineering have thought themselves bound to carry the whole responsibility themselves, when experienced help from quite another field should have been secured.

In the beginning stages of such projects geology contributes extensively to engineering success; afterward or in the end, when the ground is all exposed, both the certain and the uncertain features of it, and when the interpretations previously made can be checked against the facts actually found in construction, the engineering side balances the account fully by its contributions to a better understanding of geology.

I recall with much satisfaction, therefore, that the true nature of the first steps was realized fully by the men who began this fine piece of work.

The same wisdom has been shown by Chief Engineer Winsor in preparing for and carrying construction forward. It has been fortunate all round that one of the assistant engineers, Mr. Fahlquist, was so well prepared already and took such keen interest in the geological side of this work. This fact has made my own work lighter and has given a greater feeling of security than usual where the progress of work must be followed from a distance.

I recall that there were several alternative sites for the proposed Swift River dam. The reason why the site described by Mr. Hammond was chosen was chiefly because the physical conditions there are better, considering the purpose of the whole undertaking, than they are anywhere else along the river. The reason why the Beaver Brook dike is located where it is is because geological conditions are judged to be better at that point than at any other place. Neither of these was originally the more highly favored spot; they were not even the first spots to be tested. They are the final choice after considerable field study and exploration.

In many projects where large quantities of water are to be impounded the chief concern is with the behavior of the rock floor and side walls; in the Swift River project concern is centered almost wholly on the cross profile of the valley and on the overburden. If the character of the overburden were as good as glacial drift often is, several million dollars could be saved to the State of Massachusetts. Some one is sure to ask whether a better place could have been selected. That is a proper question, and it is essentially a geological one. If the cross profile were shallower and narrower it would also save millions. Are there places where better conditions in this respect might be found? It is a proper question also and essentially a geological one; but both have a strong engineering and an economic flavor. If a better place cannot be found, what is to be done about the one selected? Interpretation of the physical conditions then becomes the major problem. After that has been done, the rest is chiefly an engineering problem. But it has a geological flavor even then, because the conditions as they do exist must be met by the design and plans and methods of construction.

For a tunnel much the same can be said. The line can be laid out best if it is done on a series of alternatives, with reconnaissance inspections, relocations, and minor shifting to meet the demands of growing acquaintance with local geologic factors. How deep must the tunnel be placed to insure a safe roof? Is some formation likely to be encountered that will bring danger to the workmen, threaten the permanence of the structure, introduce new difficulties, or lead to excessive delay and cost? Can the engineers count on twenty-five miles of safe-going through rock that will not present unusual conditions? Can the estimates be made on that basis? How many of these elements are certain and how many are doubtful? How large a factor is on the side of doubt? Is there any way to remove virtually all of the uncertainty? Who is going to tell how to find out the answers to these questions, and where to begin and how much to do? After the tests are made who is to interpret the exploratory data in more practical terms?

I recall riding along the general course of the future Swift–Wachusett Tunnel years ago, when the only question asked was whether one could see anything that would be likely to make the project impracticable. It was a day of preliminary inspection. Is such a matter an engineering question? Certainly it is in part. Is it a geological question? Yes, it surely is in part. Such questions lie in that peculiar middle ground, often too much neglected or too often treated in a one-sided way just because they lie between, in a sort of no-man's land. This is in reality the true field of co-operative science, a form of applied science where the principles of one science join with those of another field to the improvement of the product, or to the greater safety or the greater economy of an undertaking, or to the success of a project by a direct practicable program rather than by the trial-and-error or venture-and-risk method.

I have given a reasonably long lifetime to cultivating this field. I have been especially interested in the matter as an educational and professional ideal, and it is a great personal satisfaction to find that, in this day above all other times, both the engineer and the geologist are wide awake to the great importance of the applied side of geologic science. Instead of looking on such work with disfavor, more and more geologists of standing have come to regard this particular form of activity as an excellent way of rendering lasting public service.

SLUDGE DIGESTION *

By Willem Rudolfs †

(Presented before the Sanitary Section, Boston Society of Civil Engineers, December 5, 1928)

Among a diversity of problems the question of sludge digestion has been studied in considerable detail in the laboratories of the Department of Sewage Disposal at the New Jersey Agricultural Experiment Station. During the last five years information has been gathered, and the present paper is an attempt to summarize the findings. Some of the material presented in summary form is as yet unpublished. Since this is proposed to be a summary of the work carried on in our laboratories dealing with sludge digestion, no mention will be made of studies conducted by other investigators.

It is not within the scope of this paper to give an account of the design features or operating details of the various methods employed in sludge digestion; it must confine itself to the changes taking place during decomposition processes, the organisms and their enzymes responsible for the changes, and the factors influencing the activities of the organisms. For the sake of completeness the different groups of materials coming under fresh sewage solids, activated sludge and screenings are included.

Anaërobic Digestion

Anaërobic digestion of sewage solids is essentially similar in nature in septic tanks, two-story tanks and separate sludge digestion tanks. In septic tanks and two-story tanks a part of the solids settle and are intended to remain at the bottom, where they undergo decomposition. The decomposition of the complex organic matter is accompanied by the production of intermediate and end products. Part of the intermediate and end products produced in the septic tank and two-story tanks are dissolved in the liquid, diffuse into the partly clarified sewage and pass out with the effluent. In separate sludge digestion tanks these soluble

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* Journal series paper of the New Jersey Agricultural Experiment Station, Department of Sewage Disposal.

† Chief of the Department of Sewage Disposal, New Jersey Agricultural Experiment Station.

substances are also present in the liquid, but cannot diffuse into the effluent, since the liquid is drawn off separately.

The intermediate products formed in the processes of decomposition may be classified in four groups:

1. *Nitrogen compounds*, like urea, proteoses, peptides, amino-acids and ammonia. Amino-acids may run as high as 500 p.p.m. or more, and ammonia 1,200 or more p.p.m., in the liquid.

2. *Carbon compounds*, like glucosides, etc., but those of particular interest are the organic acids. Fatty acids, like formic, acetic and butyric, are formed in some quantities, and under certain circumstances may remain as such for a considerable time. Bibasic organic acids, like oxalic, are formed in small quantities, and of the hydroxy acids, lactic acid is of special importance under certain conditions. There is no doubt that small quantities of aromatic acids (benzoic) may also be formed.

3. *Sulfur Compounds.* — Of the intermediate sulfur compounds members of the double-linked sulfur group are found. In acid sludge digestion mercaptans are formed. It is well known that mercaptans are mostly liquids with penetrating and excessively disagreeable odors. The type of odors is often indicative of the product formed. When fresh solids are digested alone, a peculiar, penetrating, sickly, onion odor develops, usually within a fairly narrow reaction range. This odor has been pronounced to be caused by allyl-sulfide. Other odors develop, with the resultant disagreeable pig pen odor. Among the intermediate sulfur compounds might also be classified H_2S, although this compound is, under certain conditions, a true end product.

4. *Phosphor Compounds.* — It is conceivable that under certain conditions intermediate phosphor compounds are formed, since phosphoproteins (casein, etc.) might either be present or be formed. Some years ago a little work was done but no definite conclusions can be presented.

It is evident, however, that almost any compound might be present or produced during decomposition.

The end products of anaërobic decomposition consist mainly of (1) gases, (2) alcohols, (3) a humus-like residue, (4) salts, and possibly some acids. The gases are mainly methane, CO_2, some H_2S and under certain conditions NH_3, and some unsaturated hydrocarbons. The alcohols consist under certain conditions of wood alcohol, acetone, glycerol. Of the salts being formed the most interesting and important are the ammonium salts. They play an important rôle in the buffering of the material. The humus-like residue is at present mainly a nuisance, although its fertilizing qualities are well known, and it is often sold as such.

Analyses of a number of sludges collected over the country show that the average nitrogen content of the sludge is about 2.5 per cent.

From this brief summing up it is evident that as soon as we do not have to devote so much time to the problem of disposing of the sewage solids, our attention must be drawn to a greater utilization of the by-products. The only by-products used at present are the gases and the dried sludge.

NATURAL CAUSE OF CHANGES

Sewage solids can be classified into three main groups:

1. Carbonaceous material (like sugars, starches, cellulose, lignins, etc.).
2. Nitrogenous material (like urea, protein, etc.).
3. Fats (vegetable, animal, mineral).

The decomposition of the different components of sewage solids under "natural" conditions is comparatively slow, and changes occurring during the decomposition processes can be followed at ease. The decomposition of sewage solids, generally termed "sludge digestion," must necessarily be complex. Nevertheless, the gross activities of the numerous species of organisms and their enzymes involved can be grouped under three headings:

1. Period of intensive acid production.
2. Period of acid regression or acid digestion.
3. Period of intensive digestion of more resistant materials.

These different stages or periods are represented by typical intermediate and end products, changes in reaction, and changes in the flora and fauna. These changes allow us an insight into the "mechanisms" of sludge digestion. Although not all factors are known, we are constantly filling the gaps of the schematic presentation published in our Annual Report for 1925–1926.

A graphic presentation of some of the intermediate and end products is given in Fig. 1. The three stages indicated above are possibly best demonstrated by the changes in pH values of the material, the gas production, and by the total carbonates and total acidity curves.

With the drop of pH values a simultaneous drop in gas production occurs. In spite of the fact that the total carbonates (mainly acid carbonates) and ammonia production curve rise sharply, the hydrogen ion concentration increases greatly, due mainly to organic acids. The accumulation of these organic acids, produced chiefly from the easily available carbohydrates (sugars, starches, that part of cellulosic material which can be extracted by Schweitzer's reagent), continues for a short time only. During the period of intensive acid production, organic acids are formed faster than they are broken down, whereas during the second stage the acids are eventually broken down faster than they are formed, and accumulated acids decrease. The rapid production of ammonia-nitrogen indicates that nitrogenous material is attacked as soon as acid accumulation stops, although during the first stage the soluble nitrogenous material is attacked, as evidenced by N-gas production, disappearance of NO_3-N, and low level of albuminoid nitrogen.

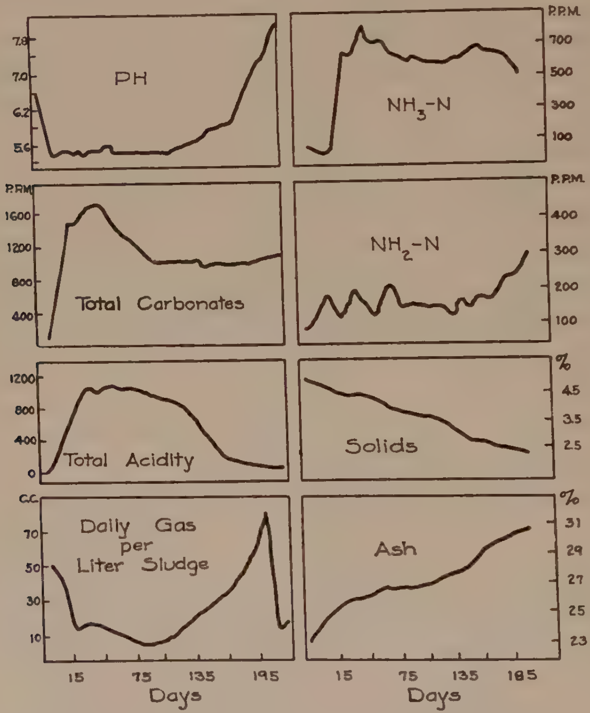

FIG. 1. — CHANGES OCCURRING DURING THE "NATURAL" DIGESTION PROCESSES

Finally, when the acid substances begin to disappear, the ammonia compounds make the medium more favorable for the decomposition of more resistant carbohydrates and fatty substances. The biological activities come to an equilibrium. The establishment of such an equilibrium or "biological balance" is necessary for maximum activity of the desired nature.

CHANGES IN FLORA AND FAUNA

The changes in flora and fauna are illustrated with a few examples in Fig. 2. After an initial drop of total bacteria, they remain at a low level during the second stage, but the proportion of H_2S producers and albumen digesters increase markedly, indicating that proteolysis increases. During the third stage the total bacteria increase rapidly, but these belong to different groups, mainly spore-forming anaërobes and fat-splitting organisms.

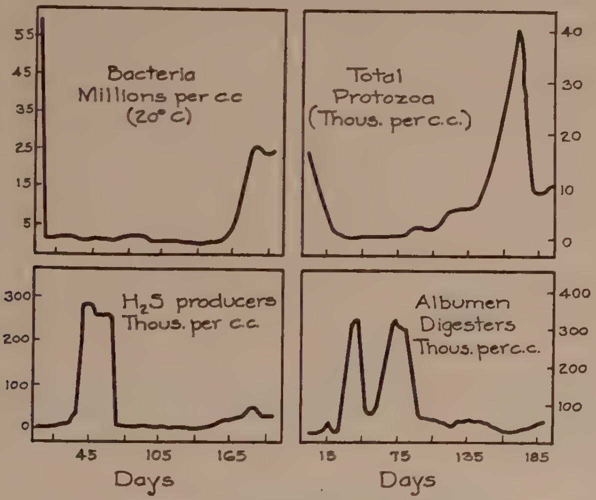

FIG. 2. — CHANGES IN THE FLORA AND FAUNA DURING THE "NATURAL" DIGESTION PROCESSES

The protozoa present, consisting mainly of Monas, Amœba (Hartmanella) Colpoda inflata, Trepomonas and small flagellates belonging to the Bodo group, disappear with the increase in acidity, and rise markedly when the organic acids begin to disappear. It is of interest to state that small quantities of organic acids (lactic, acetic, butyric) stimulate the growth of the protozoa. We have been able to increase the numbers of small flagellates with additions of 0.3 per cent lactic acid to 250,000 and more per cubic centimeter. Although we have no definite direct evidence showing the part played by the protozoa in the digestion processes, it is evident that by sheer force of their numbers they may be an important factor under certain circumstances.

Relative Abundance of Bacteria

The total numbers of bacteria per cubic centimeter of sludge or per gram dry organic matter change during the course of digestion. Since the different substances in the sewage are decomposed at a different rate during the course of digestion, the question rises as to which organisms or groups of organisms are mainly responsible for the decomposition. It is safe to say that in raw sewage solids all groups which become active are present. Reduction of total numbers is rapid at the beginning, and the maximum increase comes near the end. High numbers of organisms do not necessarily mean better digestion or greater rates of activity. Certain active groups are at the beginning overshadowed by the presence of large numbers of other forms less active. It is a tedious and long study to determine accurately even the rough physiological groups, let alone the different species. A beginning has been made in this direction, and the first physiological groups selected were the lactose fermentors. The lactose fermenting organisms embrace many organisms of different physiological and taxonomic groups. For instance, they include the intestinal organisms of the B. coli groups and the anaërobic spore-forming types. A study disclosed that near the end of the digestion processes the number of spore-forming lactose fermentating organisms constituted the majority of the lactose fermentating organisms. We have here, then, the first indication of a definite correlation between a certain group of organisms and digestion. It should be understood that no claim is made that this group is the most important one.

Enzymes

Another type of attack upon the general problem of sludge digestion is a study of enzymes present and their changes in activities. It should be remembered that enzymes are catalists which will speed up the reactions, and are produced by living organisms and cells. Bacteria produce the enzymes and are also the carriers of the enzymes. The different enzymes are affected by temperature, reaction of the medium, end products formed, etc. There is some information regarding the presence of enzymes in crude sewage which are presumed to convert the high molecular suspended and pseudo-colloidal material into liquids, but to our knowledge nothing is known about the types and their variations in abundance during the digestion processes, and what the optimum conditions are in sludge for their greatest activities.

Of the enzymes present during digestion might be mentioned particularly: diastase, lipase, pepsin, trypsin, catalase, invertase, rennet and lecithinase. The latter seems to be present only in small quantities, and the occurrence and the variation of some of the others are graphically shown in Fig. 3. For comparison and as an indication of the rate of digestion of properly seeded fresh solids, incubated at 80° F., the daily gas production per gram volatile matter is given. It will be seen that the rennet activities decrease rapidly. Trypsin increases rapidly and reaches a peak within a few days, followed by a peak of pepsin, and this

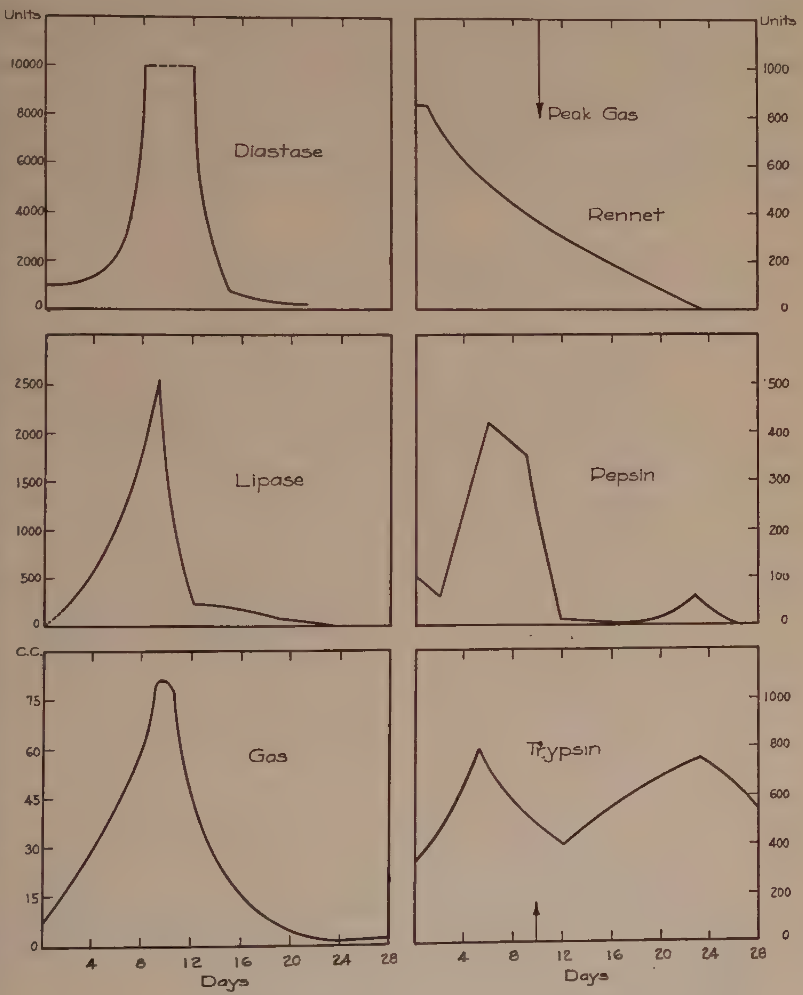

FIG. 3. — OCCURRENCE AND FLUCTUATIONS OF ENZYMES IN PROPERLY SEEDED MIXTURES DURING DIGESTION

is followed by a maximum of lipase activities which coincides with the peak of gasification. Diastase reaches its highest at the peak of gasification, but remains longer at a high value than the lipase. Trypsin reaches a peak before gasification, and has another peak when gasification is well over. Catalase, although present, is not of particular interest in anaërobic sludge digestion. The reason for the decrease in rennet is obvious, since it acts on soluble nitrogenous substances. Diastase acts on carbohydrates, pepsin and trypsin on nitrogenous substances, and lipase on fats. These curves afford an excellent confirmation of what has been previously stated, namely, that first are attached soluble nitrogenous substances like urea, followed by easily decomposable carbohydrates. These are followed in turn by more resistant nitrogenous substances, and finally by more resistant carbohydrates and fats.

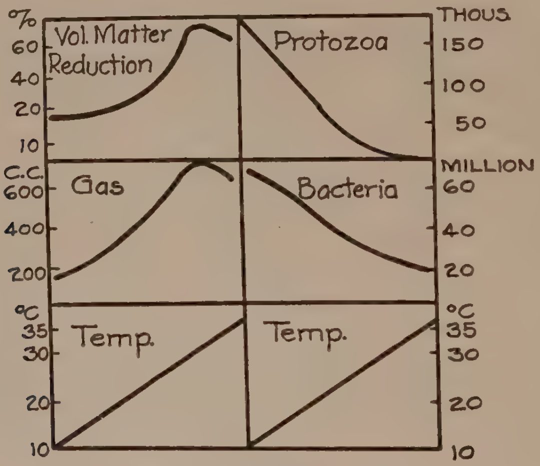

Fig. 4. — Effect of Temperature on Rate of Digestion

Results on the effect of single enzymes and mixtures of enzymes upon the rate of decomposition of sewage solids are made ready for publication.

Effect of Temperature

An important factor influencing the rate of activities of the organisms is temperature. Fig. 4 shows clearly that up to a temperature of 30° destruction of organic matter increase at an accelerated rate, accompanied under certain circumstances by a higher rate of gas production. It should be understood, however, that volatile matter reduction is not always accompanied by gas production. Under certain conditions the organic matter is changed to substances which are volatile upon drying, but produce no gases while digesting.

It could be assumed that with a greater volatile matter reduction and greater gas production the numbers of bacteria increased. This is not necessarily true, if we keep in mind that temperature does not affect all organisms in the same way. Even if temperature affected all organisms alike, the activities of those organisms for the destruction of the more resistant substances would make the medium unfavorable for those organisms initially present, which are not actively engaged in the particular digestion processes involved.

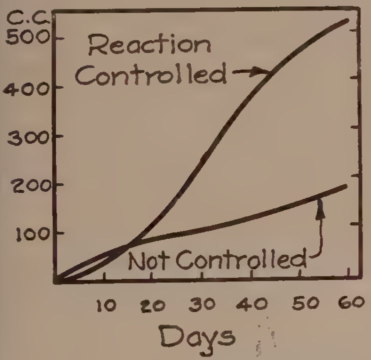

FIG. 5. — EFFECT OF REACTION CONTROL ON THE RATE OF DIGESTION

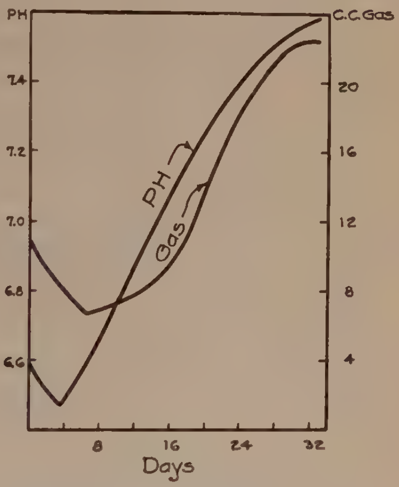

FIG. 6. — RELATION BETWEEN REACTION AND GAS PRODUCTION

EFFECT OF REACTION

In the foregoing discussion attention has been drawn to the correlation between changes in reaction and activities of the microbial flora. Fig. 5 shows an example of the accumulated gas production from a mixture of sewage solids with the reaction controlled by means of hydrated lime, and another digesting under "natural" conditions. Although lime retards initial gas production, the amounts produced after sixty days with the reaction controlled by lime additions is more than two and one-half times the quantity produced from the unlimed material. The relation between gas production and the reaction of the material is more clearly shown in Fig. 6. Gas production follows rapidly the changes in reaction of the medium. Gases produced from material with low pH values have large percentages of CO_2 (sometimes as high as 55 per cent), H_2 (8 to 15 per cent), and N_2, whereas gases from sludge with high pH values have high percentages of CH_4 (70–75 per cent), low CO_2 (15 to 18 per cent), no H_2, and low N_2.

Effect of Inoculation

The most important single factor is inoculation of raw sewage solids with sludge that has undergone decomposition. Such sludge has a flora which is well balanced and counteracts the effects of intermediate decomposition products during the early stages of digestion. The effect of inoculation is demonstrated in Fig. 7, where reaction and gas production curves plotted from results obtained from inoculated material are compared with results from mixtures not inoculated. Attention is drawn to the fact that the total quantity of gas produced per gram organic matter is not influenced by inoculation, but material not inoculated required about six times longer for incubation than does properly inoculated sludge.

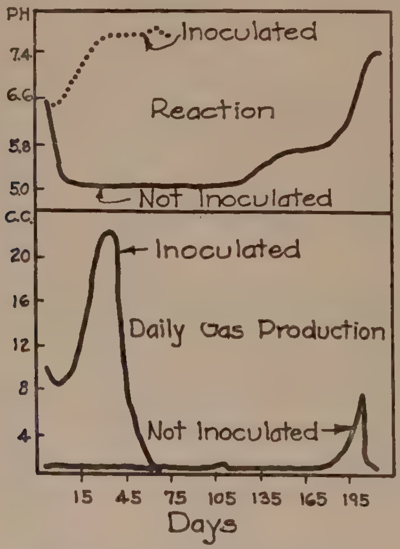

Fig. 7. — Effect of Inoculation on the Rate of Digestion

Function of Ripe Sludge

The function of ripe sludge, ordinarily spoken of as "seeding" or inoculating material, is in effect manifold. Fresh solids seeded in proper proportions with ripe sludge digests at a temperature of 70° F. in from thirty to forty days. As soon as the amounts of ripe sludge are materially decreased the length of time required to complete digestion is greater. It has been found that under ordinary circumstances not more than 2 per cent fresh solids (dry basis) can be added daily, but under more favorable conditions, like higher temperature, the amounts can safely be increased to 3.5 per cent, or a digestion schedule of about thirty days. The question arises, however, can we use any kind of old sludge, or does ripe sludge lose its seeding value? It has been shown by laboratory experiments that ripe sludge does not retain its seeding value and should not be older than two to three months. Offhand, it would seem that the organisms responsible for the decomposition in the last stages of digestion disappear when the available food supply is practically exhausted. This available food supply is apparently only a part of the total organic matter, since about 50 per cent of the original organic matter is left as residue — the humus-like sludge — and withdrawn. Although an abundance of bacteria does not necessarily mean rapid digestion, low numbers of bacteria usually mean fairly inactive substances. Ripe sludge drawn shortly after the peak of activities are over may contain up to 45,000,000 bacteria per cubic centimeter. This same material stored for two and one-half to three years contains only a few hundred thousands of bacteria per cubic centimeter, with 46 to 47 per cent of the original volatile matter left.

A partially decomposed material is poor for seeding purposes. Yet such material may contain considerable more organisms per cubic centimeter or per gram dry material than ripe sludge. In addition, it may have as high or higher alkalinity and contain more colloidal substances than ripe sludge.

Buffer Action

The function of ripe sludge is in no small measure linked up with its buffer action. As has been pointed out before, considerable quantities of CO_2 are produced which dissolve partly into the liquid. As a matter of fact, as high as 85 to 90 per cent of the acidity produced during digestion might be due to CO_2. Part of this CO_2 combines with the ammonia, forming ammonium carbonates. When the material is improperly seeded, ammonia production takes place at a slower rate, with the result that the dissolved CO_2 makes the medium acid. In this acid medium the carbonaceous substances are broken down, forming organic acids which remain to a large extent, because the conditions are then unfavorable for the activities of the organisms decomposing the nitrogenous substances. The final result is that we have an acid material in which the digestion activities are retarded. To overcome this retardation an alkaline substance is added, usually lime. It explains, also, why properly seeded mixtures do not require reactions adjustment. The "natural" buffering effect of the sludge is therefore a very important function, and it is logical that better buffering substances than hydrated lime should be more beneficial. That this is actually the case is shown in the following few figures. Unseeded material was used, and after thirty-three days of digestion the percentages volatile matter reduction were as follows:

1. No reaction adjustment, 13.5 per cent.
2. Hydrated lime added, 19.7 per cent.
3. Lime and buffer added, 24.8 per cent.

The buffer used consisted of NH_3, HCO_3, NH_3CO_3 and K_2HPO_4. In addition to the greater volatile matter reduction, the material treated with lime and buffer solution had to be adjusted only once, whereas with lime alone the reaction had to be adjusted daily.

EFFECT OF TRADE WASTES

Little direct and reliable information concerning the effect of trade wastes upon sludge digestion is available. To a limited extent we have studied the effect of salt, H_2SO_4, dye waste, alkalies, laundry waste; and detailed studies have been made on the effect of milk waste, vegetable waste, different forms of sulfate wastes, and especially the effect of different forms of iron. In general, it might be said that small amounts of trade wastes have but little effect upon the digestion processes; larger quantities are as a rule detrimental. The most interesting wastes received at a plant are the iron wastes. If the quantities present are not too large, sedimentation is increased, odors are diminished, and the rate of digestion might be increased. As an example we might use sewage solids collected at Trenton, New Jersey, where considerable quantities of pickling liquors are received, and compare them with Plainfield, New Jersey, fresh solids, where no such wastes are present. The comparison is made on properly seeded material incubated at 80° F. A summing up of the data secured on one particular experiment is given in Table I. It might be added that (1) fresh solids digested alone, (2) in combination with other materials, digested at different temperatures, (3) with reaction control, all show the same general results.

Table I. — Difference in Plainfield and Trenton Sludge

	Plainfield	Trenton
Per cent ash in solids	22.2	42.1
Per cent Fe in dry solids	4.20	10.1
Relation volatile matter to Fe	18.5:1	5.7:1
Per cent sulfates in dry solids	1.40	5.06
Cubic centimeters gas per gram solids	463	430
Cubic centimeters gas per gram volatile matter	720	720
Peak of gas after days	12½	7½
Ready to draw	27	21
Per cent solids reduction	30	20

The percentage ash in the Trenton solids is nearly double that of the Plainfield solids, consequently the percentage solids reduction in the Trenton sludge cannot be as large. Gas production per given quantity dry solids is lower from Trenton sludge, but attention is drawn to the fact that the quantities of gas per gram volatile matter are the same in both cases. The digestion time for Trenton sludge is materially less than for Plainfield sludge, amounting to, roughly, 25 per cent. This would mean that Trenton can get away with 25 per cent less digestion capacity than Plainfield. Sulfates, always a potential source of odors, are much higher in the Trenton sludge, but on account of the iron present odors from the digesting mixtures are less. Studies dealing with the effect of different forms of iron compounds will be reported upon within a short time.

Effect of Oils and Grease

Even large quantities of mineral oils have practically no effect upon the course or rate of digestion of sewage solids digestion. However, it is advisable to keep mineral oils out of digestion tanks on account of difficulties in handling and unsightly masses. The effect of greases, soaps, etc., is more pronounced. Under ordinary circumstances, greases decompose during the last phases of the digestion processes, and subsequently large quantities of grease have the tendency to increase the time required for digestion.

The composition of the gas produced seems to be influenced by the grease content, and more particularly by the rate of decomposition of the grease. In an experiment lasting for a number of months, with daily additions of fresh sludge, the material added and withdrawn was also analyzed for its grease content. If the percentage grease reduction is plotted with the CO_2 content of the gas, a direct relation is established. In Fig. 8 the monthly average of the percentage reduction in grease is plotted with the percentage CO_2 in the gas. The relation seems obvious.

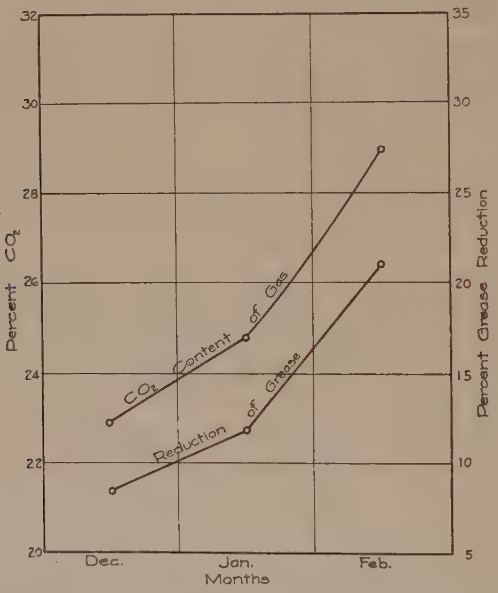

Fig. 8. — Relation between the Rate of Decomposition of Grease and CO_2 Production

Digestion of Activated Sludge

In the January, 1929, issue of the new "Sewage Works Journal" a semi-plant experiment will be reported dealing with activated sludge. The results show that activated sludge digests more rapidly than fresh sewage solids. This would seem to be logical, since a part of the easily oxidizable material present in the sewage is removed, and does not give rise to the same quantities of organic acids and other acid substances. Even of greater interest is the fact that greater additions of activated sludge can be made than is the case with fresh sewage solids. The difference is quite large. At a digestion temperature of 82° F. from 3.5 to 4.0 per cent dry fresh sewage solids can be added daily, and in the case of activated sludge from 5.5 to 6.0 per cent can be added daily, with the result that a digestion schedule of from seventeen to eighteen days can be maintained instead of thirty-two to thirty-five days with fresh solids. Gas production from activated sludge is somewhat less than from fresh solids. These results have borne out our laboratory experiments, which unfortunately are still awaiting publication.

Digestion of Screenings

After considerable laboratory work was performed on the digestion of screenings, vegetable wastes, etc., experiments on a semi-plant scale were conducted under our direction at Milwaukee, where daily an amount of screenings were added representing the waste of about 550 persons. The daily addition of screenings was continued for about six months, and a digestion schedule maintained of forty days. The solids reduction was naturally high (61 per cent), since the ash content of the screenings is low (about 9 per cent). With this digestion schedule of forty days, decomposition of total organic material amounted to 66.8 per cent, of nitrogenous substances to 59.5 per cent, and fatty substances to 56 per cent. The digested material drained readily and was spadable in from three to four days. The effective digestion capacity required was calculated to be about one gallon per capita.

Digestion of Screenings Mixed with Activated Sludge

In the activated sludge process, where necessarily fine screens are employed, roughly, from 10 to 20 per cent (usually from 9 to 13 per cent) fine screenings are collected. In some instances these screenings are buried or placed in a pit. The question of digesting the screenings together with activated sludge is of some practical importance. Experiments made show that if properly seeded activated sludge digested alone at 70° F. requires thirty days, a replacement by 10 per cent screenings would require about thirty-five days, and a replacement of 20 per cent activated sludge by an equal percentage screenings, about forty days. Naturally, more gas is produced per gram dry material when screenings are added, — the increase in volume of gas is proportional to the increase in screenings.

Summary

Summarizing this summary on the changes during the decomposition process of sewage sludge, the organisms and their activities, and some of the factors influencing the activities, we might state:

1. The gross changes occurring during digestion might be placed into three not distinctly separate groups: (*a*) periods of intensive acid production; (*b*) period of acid regression; and (*c*) period of intensive digestion.

2. Bacteria and their enzymes fluctuate, but certain physiological groups follow each other.

3. There is no definite direct evidence that protozoan activities are of importance, but under certain conditions they may be important by the force of their numbers.

4. Of the factors influencing the rate of digestion, inoculation is of prime importance, followed by temperature and reaction. Trade wastes might affect digestion, either favorably or unfavorably.

5. Other groups of complex organic substances — segregated like screenings, or produced by a different process like activated sludge — digest essentially in a similar way as plain settled fresh sewage solids.

OF GENERAL INTEREST

CONTRACTOR OR CONSTRUCTOR?

By Edward Grossman *

These are days of purity in nomenclature. In ancient days we had only civil and military engineers. With the coming of the locomotive came the locomotive engineer, now fast changing into a motorman with the increasing use of electric traction in various forms, and now we have all kinds of engineers. They run the gamut from agricultural to X-ray, and possibly zoölogical engineers. Every one specializes and every one takes the utmost care to define his occupation so that he may not be mistaken for something else. There is a class of professionals, however, which is engaged in work that is a branch of engineering, but travels under a misnomer. We have with us the class of people known as contractors.

The art of construction is an ancient one. When one of our prehistoric ancestors conceived the idea of placing a stick across two saplings standing close together, in order to form a support for the roof of his shelter, he was an engineer, although he did not know it, for he invented the beam and the strut. Immediately thereafter he put his plan into execution and became a constructor. No doubt he was proud of himself and took care to let everybody know it. His descendants, however, are not proud of themselves, apparently; for if they were, they would not call themselves contractors.

The name of the constructor's occupation is a misnomer. A contractor is not necessarily a constructor; a contractor is merely one of the signers of a contract. But the constructors have let this error persist, and, because of the actions of some of the contracting gentry of a generation or two ago, the public has come to have a wrong conception of the constructor.

We all know of the bluff and corpulent man of years ago who rose from the pick and shovel job, or from carpentry, or bricklaying, and became a contractor. We see him once in a while, — some examples of him are still left, — and we know that he is what the "man in the street" thinks of when he hears the word contractor. He is an unbusinesslike man, is this contractor, who carries his office in a combination time book, ledger, and *vade mecum* in his hip pocket, and a thick black cigar between his teeth.

To those in the profession he is a passing figure, soon to be extinct. His rough-and-ready methods will not let him survive. To the public, however, this gentleman is the type that builds bridges, buildings, waterworks and railroads. Show a layman a thin person, whose speech may be halting, who is dressed as quietly as a banker, and tell him that this man is a contractor. The layman may be too polite to laugh at you, but he will raise his eyebrows. What! A small, slight man a contractor? Perish the thought! A contractor is a fat man who always needs a shave, has a black cigar in his mouth, and goes through the soup course as quietly as a diaphragm pump sucking the last quart of water out of a hole. Yes, to the lay mind all contractors, like all politicians (with whom they seem to be in close contact), are fat, disgusting persons, more than a little grasping in their business habits.

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* With Benjamin Steinberg, 6 Beacon Street, Boston, Mass.

Long ago it may have been true that the contractor was a two-fisted, ignorant chap whose business died when he died; but it is not the case now. A constructor nowadays has an organization; he runs his business as it should be run — as an administrative branch of the science of engineering. The engineer is the specialist in design; the constructor is the specialist in construction. This is appreciated by the successor to the fat man of ancient days. He does not, however, seem to appreciate that the word contractor, which he uses to describe his occupation, is utterly obsolete.

It is very probable that the term "contractor" was applied as a temporary name, and the fat men of ancient days did not know any better than to carry it along. The specialized administrative and engineering functions of the modern construction staff deserve better than the misnomer under which they labor at present; they deserve a change for the better.

One who builds or constructs should be called a constructor.

It is gratifying to see that some of the more progressive building constructors are breaking away from the obsolete term. They have found that as an identification of their business it is useless, for every one who is able to furnish any commodity in quantities may with right call himself a contractor, since he may sign a contract to furnish that commodity and legally become a contractor. But, although he may legally be a contractor, it does not follow that he can do engineering construction.

In a recent classified directory of one of our large cities, eighteen kinds of businesses were sandwiched in between engineering constructors under the classification "contractors," and it is presumed that they are all able to construct engineering works, else they would not be listed. The following are businesses that are also "contractors:" cesspool cleaners, cinders dealers, concrete block manufacturers, concrete form manufacturers, cut stone dealer, electricians, excavators, garbage container manufacturer, heating contractor, office fixture dealers, oil burner manufacturer, real estate men, refuse collectors, sand and gravel dealers, steel column manufacturers, steam shovel dealers, steel erector, wreckers of buildings.

Out of the eighteen given above only two or three cannot by any stretch of imagination be called contractors. All the rest may sign contracts to furnish their commodities in quantity and become contractors in the legal sense, although not in the sense understood by the general public, which considers a contractor one who can construct engineering works. Is it any wonder that there is such a howl about irresponsible bidding and cut-throat competition? Yet the fault is with the construction men. The real estate men, confronted with a similar problem, apparently solved it, for now we have the word "realtor." There is no reason why constructors cannot solve their problem, also. All that is required is the adoption of the name constructor and a little campaign of education and the public will fall in line.

MEMOIR

Professor Peter Schwamb*

DIED NOVEMBER 3, 1928

PROFESSOR SCHWAMB was born in Arlington in 1858, where he received his early education in the public schools. He graduated from the Massachusetts Institute of Technology with the class of 1878.

Immediately after graduation he was employed by the Howe Scale Company at their works in Vermont, and later he worked as draftsman and designer for the Hinckley Locomotive Works. He returned to the institute as an instructor in mechanical engineering and director of the School of Mechanic Arts in 1883. He was made an assistant professor in 1884, associate professor in 1888, and a full professor in 1896, which position he held up to his voluntary retirement on account of disability due to deafness in 1911.

It was largely through Professor Schwamb that the mechanic arts work at the institute developed to the high rate of efficiency which it had at the time of his retirement. As an instructor in mechanism, machine design, and textile machinery he had no peer. His enthusiasm for his work was transmitted to his students, who day after day would cut their lunch hour to fifteen minutes in order to devote the time to machine design. He was never too busy to help a student; and, through his courtesy, kindness and advice, he became one of the most loved and respected professors in the department. It was a distinct loss to Technology when the partial loss of hearing made it necessary for him to give up active work at the institute.

Since retiring from the institute, Professor Schwamb gave a great deal of service to the town of Arlington which has had, gratuitously, his services as an expert engineer, serving the town as a member of the school committee, as water commissioner, and as chairman of the Board of Public Works.

Professor Schwamb is survived by a wife, two sons who are graduates of Technology, and a daughter.

An article in "The Technology Review," written by Professor Merrill at the time of Professor Schwamb's retirement, contained this tribute:

> It is difficult to estimate the influence of a man like Professor Schwamb upon those about him. The pupils in his classes, as well as his associates in work, have never failed to catch the inspiration which came from dealing with a teacher of his type. His clear grasp of fundamental principles, his broad, practical knowledge of their application, and his untiring devotion to work have left an impress which nothing can efface upon a great body of former students extending back over a period of nearly thirty years. Better than this, his sterling honesty, his unfailing sincerity, and his vigorous manliness have found a ready response in the moral life of his former pupils. No teacher in the institute has been more earnestly sought by returning alumni than has Professor Schwamb, and his wise counsel has proved a source of great strength to many a former student.

Professor Schwamb was elected a member of the Boston Society of Civil Engineers on May 16, 1894.

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* Prepared for the faculty of the Massachusetts Institute of Technology by E. F. Miller, C. F. Park and G. B. Haven.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Boston Society of Civil Engineers

DECEMBER 19, 1928. — The regular meeting of the Boston Society of Civil Engineers was held this evening in Chipman Hall at 7.15 P.M. and was called to order by the President, C. B. Breed. One hundred and twenty-five members and guests were present.

The Secretary reported the names of those elected to membership today by the Board of Government:

Grade of Member: Hartwell H. Crossman,* John A. Howe,* Kenneth G. Hulsman, Benjamin Rubin,* Henry X. Wyner.* *Grade of Junior:* Charles K. Brown, Orall J. Calderara, David Cohen, Karl Gregory, Fred E. Hess, Laurence H. Willis.

The President announced the death of the following members of the Society:

Frederick W. Huntington	Nov. 19, 1927
Richard A. Hale . . .	Dec. 17, 1928
Peter Schwamb . . .	Nov. 3, 1928
Howard C. Thomas . .	Dec. 10, 1928
Gilbert S. Vickery . .	July 2, 1928

The Secretary reported that the Board of Government had voted to omit the regular meeting of the Society for January (January 23, 1929) on account of the affiliation meeting on aviation which is to be held February 6, 1929. This meeting will consist of technical sessions in the afternoon, followed by the annual engineers' dinner, at which there will be speakers of national prominence on some of the more general phases of aviation.

The President then presented Dr. Miller McClintock, Director, Erskine Bureau, Harvard University, who spoke on "Traffic Control Engineering." Dr. McClintock has had a broad experience in connection with traffic control, and has been consulted on traffic problems in many large cities of this country.

In addition, he discussed the general phases and referred to the comparatively recent report of the Traffic Committee for Boston, prepared under the direction of the Erskine Bureau.

Mr. M. N. Halsey, Traffic Engineer in the Massachusetts Department of Public Works, described the work which is being done by the Department in co-ordinating traffic control in various cities and towns in the Commonwealth.

Following Mr. Halsey's talk a general discussion was held in which William F. Williams, Commissioner of Public Works, and a number of others took part.

J. B. BABCOCK, *Secretary.*

Sanitary Section

DECEMBER 5, 1928. — The meeting of the Sanitary Section was held in the Library of the Affiliated Technical Societies at 7.15 P.M., on Wednesday, December 5, 1928.

Twenty-nine members and guests attended the informal dinner preceding the meeting at Warmuth's Restaurant.

The Chairman called the meeting to order and introduced Dr. Willem Rudolfs, Chief of the Department of Sewage Disposal, New Jersey Agricultural Experiment Station, who gave an illustrated talk on "Sludge Digestion."

This talk brought out a lively discussion which was participated in by many of the members.

The question of the formation of a New England Sewage Operators Conference was discussed, and a motion was made and passed that the Chairman appoint a committee to submit a report at the next meeting of the Section.

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* Transferred from Grade of Junior.

The meeting of 51 members and guests adjourned at 9.50 P.M.

STUART E. COBURN, *Clerk.*

Designers Section

DECEMBER 12, 1928. — The meeting was called to order at 6.15 P.M. by Chairman W. D. Henderson. At this time he announced the recent death of Mr. Howard C. Thomas, a charter member of the Section.

Major L. B. Lent, Engineer of the Common Brick Manufacturers' Association of America, was introduced as the principal speaker of the evening. He emphasized the technical properties of brick as well as their other better known qualities. Numerous slides were used to illustrate his talk.

Mr. W. Gardner Long, President of the Brick Manufacturers' Association of New England, followed with a detailed description of eastern bricks, their manufacture, and new developments in their use.

The discussion which followed was one of the best that has taken place at any recent Section meeting.

After a rising vote of thanks to the speakers by the thirty-five members and guests present the meeting adjourned at .30 P.M.

NORMAN P. RANDLETT, *Clerk.*

JANUARY 9, 1929. — Chairman W. D. Henderson called the meeting to order at .10 P.M. The minutes of the December meeting were read by the clerk and accepted. At this time the postponement of Dr. Terzaghi's paper, scheduled for this date, was explained by Mr. Henderson.

Associate Professor W. M. Fife of the Massachusetts Institute of Technology, who was the speaker, had as his subject Elastic Load Method of Computing Deflection of Joints of Trusses." Professor Fife had prepared some notes on the theory of the method, copies of which were distributed as long as they lasted. He accompanied his talk by working out an example on the blackboard.

The meeting adjourned at 7 P.M., after a rising vote of thanks had been given to Professor Fife by the fifty members and guests present.

NORMAN P. RANDLETT, *Clerk.*

Northeastern University Section

DECEMBER 6, 1928. — The Northeastern University Section of the Boston Society of Civil Engineers held an interesting meeting Thursday, December 6, 1928, at 7.30 P.M. in Room 26 of the Huntington Building, with H. L. Burton presiding.

The speaker of the evening was Mr. Maxwell N. Halsey of the Albert Russel Erskine Bureau of Harvard University. Mr. Halsey spoke on "The Principles of Traffic Control." Mr. Halsey first gave a short history of traffic engineering. He pointed out the fact that traffic control formerly was done by guesswork. The present procedure is to first locate the basic problem and then to make a careful study of the solution. The speaker also pointed out that, owing to a lack of uniformity of methods of traffic control in the various cities and towns of the Commonwealth, the State is now endeavoring to draft a uniform State traffic code.

Mr. Halsey is now engaged in the drafting of such a State traffic code. In his talk he very interestingly pointed out the method and means by which such a code is being formulated.

After the talk the meeting was opened for a general discussion.

Previous to the meeting the members had supper at the Café de Paris.

H. L. BURTON, *Clerk, pro tem.*

APPLICATIONS FOR MEMBERSHIP

[January 20, 1929]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission.

Backes, William J., Winchester, Mass. (Age 49, b. Hartford, Conn.) Graduate of Yale University. Experience: 1899–1905, employed in engineering corps, Mexican International Railway, Pennsylvania Railroad, New York, New Haven & Hartford Railroad; 1905–06, assistant engineer, Pennsylvania Tunnel and Terminal Company; 1906–13, chief engineer, Central New England Railway; 1913–22, engineer, New York, New Haven & Hartford Railroad; 1922–25, assistant general manager, New York, New Haven & Hartford Railroad; 1926 to date, chief engineer, Boston & Maine Railroad. Refers to *C. B. Breed, B. W. Guppy, L. E. Moore, E. H. Rogers, F. C. Shepherd.*

Caldon, Deforest H., Gardner, Mass. (Age 24, b. Gardner, Mass.) Is a student at Northeastern University. Refers to *H. B. Alvord, C. O. Baird, C. S. Ell, J. W. Ingalls.*

Cikins, Harry, Dorchester, Mass. (Age 32, b. Odessa, Russia.) Graduate of Northeastern University, Class of 1917. Experience as follows: resident engineer, Massachusetts Highway Commission, 1917 and part of 1918; transitman, Merchants Shipbuilding Corporation, 1918; took an intensive course in naval architecture at Massachusetts Institute of Technology in 1918; structural draftsman, Bethlehem Shipbuilding Corporation, 1919, 1920 and part of 1921; draftsman, Boston & Maine Railroad, 1921–23; in business for self, 1923–26; structural draftsman with Stone & Webster, power house construction, 1926–27; draftsman in bridge department, Boston & Maine Railroad at present. Refers to *M. W. Christie, B. W. Guppy, K. G. Palm, J. J. Rourke.*

Crockett, Richard P., Boston, Mass. (Age 20, b. South Paris, Me.) Student at Northeastern University. During co-operative periods has been employed in the engineering department of the Massachusetts Department of Public Works, and at present as a transitman. Refers to *H. B. Alvord, C. O. Baird, J. W. Ingalls, W. E. Nightingale.*

Davis, Stuart Sprague, Swampscott, Mass. (Age 27, b. Peabody, Mass.) Studied at University of Maine, 1919–20; structural draftsman with Stone & Webster, 1921–26; Tufts College, 1926–28; at present with Stone & Webster. Refers to *R. E. Baker, S. K. Cohen, W. M. Gooden, J. A. Howe, R. G. Stafford.*

Greenleaf, John Whittier, Jr., Brookline, Mass. (Age 20, b. Springfield, Mass.) Am a student at Northeastern University. During the co-operative periods have been employed twenty-one weeks by the town of Stratford, and the city of Waltham twenty-one weeks, and at present am working as instrument man for city of Waltham. Refers to *W. J. Alcott, C. O. Baird, C. S. Ell, J. W. Ingalls.*

Haertlein, Albert, Cambridge, Mass. (Age 33, b. Alton, Ill.) Received degree of A.B. from Harvard College in 1916, and B.S. in civil engineering in 1918 from Massachusetts Institute of Technology. From May, 1918, to September, 1919, in United States Army as first lieutenant in Corps of Engineers; from September, 1919, to June, 1923, instructor in civil engineering at Harvard Engineering School; June, 1923, to April, 1925, structural engineer with Dwight P. Robinson & Co., New York; leave of absence from August, 1923, to March, 1924, to assist Professor Swain on work for city of New York; April, 1925, to September, 1928, uperintendent of plans and schedules ivision, Duquesne Light Company; Sep-ember, 1928, to date, on leave of absence om Duquesne Light Company to teach t Harvard Engineering School. Refers o *G. M. Fair, H. J. Hughes, L. J. John-on, H. M. Turner.*

HARMON, RUSSELL SANBORN, Auburn-ale, Mass. (Age 28, b. Stoneham, Mass.) raduate of University of New Hamp-nire in 1922 with degree of B.S. in engi-eering; 1922–23, instructor in Kentucky igh School; June 20 to December 8, 923, field engineer; December 17, 1923, o June 21, 1924, with Amos Manufac-uring Company; June 23, 1924, to ecember 31, same year, engineer on Western Avenue bridge; January 1 to pril 6, 1925, quantity surveys and esti-ates; April 6, 1925, to April 17, 1926, ith T. Stuart & Son Company; April 11, 1926, to date, superintendent for . Stuart & Son Company. Refers to *rwin Harsch, Beardsley Lawrence, J. D. avage, F. H. Stuart.*

HUNT, MAURICE F., Gardner, Mass. Age 21, b. Kingfield, Maine.) Entered ortheastern University September, 1926. uring co-operative periods has been mployed by Metcalf & Eddy, town of ramingham, and Massachusetts De-artment of Public Works. Refers to *H. B. Alvord, C. O. Baird, C. S. Ell, J. W. ngalls.*

KELLEHER, CORNELIUS PAUL, Fitch-urg, Mass. (Age 23, b. Fitchburg, Mass.) He is a student at Northeastern University and during co-operative periods as been employed by the Gleason En-ineering Corporation at Wellesley since eptember, 1926, and through the sum-ners. At present is a transitman with his corporation. Refers to *H. B. Alvord, C. O. Baird, W. H. Gleason, J. W. Ingalls.*

LEAVITT, ORAL, Everett, Mass. (Age 3, b. St. Paul, Minn.) Student at Northeastern University. During co-op-rative periods has been employed by spinwall & Lincoln for the past three ears. Refers to *W. J. Alcott, H. B. Al-ord, C. O. Baird, W. E. Nightingale.*

LORD, HOWARD F., Chelsea, Mass. Age 20, b. Chelsea, Mass.) Am a student t Northeastern University. During co-perative periods have been employed by Philip J. Leary, C.E., of Lynn; H. F. Pierce, C.E., of Boston, and E. W. Branch, C.E., town of Milton, sewer department. Refers to *C. O. Baird, J. W. Ingalls, C. F. Joy, Jr., L. C. Latimer.*

MCCARTHY, JAMES ANTHONY, Dorchester, Mass. (Age 22, b. Revere, Mass.) With Bay State Dredging Company, as field engineer, summer of 1927; summer of 1928, instructor at Massachusetts Institute of Technology summer camp; graduate of Massachusetts Institute of Technology in 1928; at present, assistant in civil engineering department at Massachusetts Institute of Technology. Refers to *J. B. Babcock, C. B. Breed, J. W. Howard, C. M. Spofford, Hale Sutherland.*

ROSENBERG, BENJAMIN ROBERT, Winthrop, Mass. (Age 35, b. Siberia.) Graduate of Massachusetts Institute of Technology in 1916. Experience: 1916–17, with Virginia Bridge & Iron Company; 1917–18, with Stone & Webster; 1918, with United States Naval Reserves, engineering department; 1919–20, with Johnko Shipbuilding Corporation; 1921–23, with S. S. Eisenberg; 1923–26, as manager with Pontiac Manufacturing Company; 1927, with Stone & Webster; 1927–28, with Boston & Maine Railroad; and to date, chief draftsman in the bridge department, Boston & Maine Railroad. Refers to *M. W. Christie, B. W. Guppy, K. G. Palm, J. J. Rourke.*

SLAYTER, RUDOLF STONE, Boston, Mass. (Age 30, b. Cambridge, Mass.) Educated in Lowell Institute and University of Arizona. Employed as chief of party, February, 1922, to September, 1924, in Detroit, Mich.; in Massachusetts Institute of Technology, 1924–28; chief of party with A. C. Peters, Boston, for six months; inspector, town of Milton, three months (summer of 1927); assistant engineer, town of Milton, since July, 1928. Refers to *J. B. Babcock, H. K. Barrows, C. F. Joy, Jr., L. C. Latimer, R. G. Tyler.*

STAMP, ALFRED THOMAS, Neponset, Mass. (Age 20, b. Barrington, R. I.) Graduate of Mechanic Arts High School in 1926 and went to work for Edison Electric Illuminating Company as assistant operator in the Hawkins Street power station. Entered Northeastern University in January, 1927, and during co-operative periods have been employed by Henry F. Bryant, and on various engineering jobs as rodman, and am now running a transit. Refers to *C. O. Baird, H. F. Bryant, W. A. Bryant, J. W. Ingalls.*

STONE, VERNON LAWRENCE, Brookline, Mass. (Age 23, b. Washington, Mass.) Am a junior at Northeastern University, and during co-operative periods have been employed by the Springfield Gas Light Company, and worked a year as rodman before coming to college. Am now transitman with the Springfield Gas Light Company. Refers to *W. J. Alcott, C. O. Baird, C. S. Ell, J. W. Ingalls.*

THRASHER, CHARLES EDWARD, East Saugus, Mass. (Age 54, b. Springfield, Mass.) Worked with his father as a builder for about thirteen years; has been an estimator for about ten years, and for the last fifteen years has been employed by George B. H. Macomber Co. as estimator and supervisor of buildings. Has had the equivalent of a high school education and studied structural engineering for three years at Northeastern Polytechnic School. Refer to *B. S. Brown, O. D. Chiesa, W. M. B. Freeman, Edward Grossman.*

WAGNER, FREDERICK WILLIAM, Brookline, Mass. (Age 24, b. Nyack, N. Y.) Entered Northeastern University in January, 1927. During co-operative periods has had experience as assistant to the town engineer at Norwood. Refers to *W. J. Alcott, C. S. Ell, J. W. Ingalls, L. D. Thorpe.*

WOOLF, ABRAHAM, Dorchester, Mass. (Age 21, b. Boston, Mass.) Graduate of Massachusetts Institute of Technology in architectural engineering. Employed by New England Wood Preserving Company as draftsman, and by Mark Linenthal as designer and draftsman. Refers to *K. R. Garland, W. H. Lawrence, Dean Peabody, Jr., Charles Terzaghi, A. I. Wistreich.*

For Transfer from Grade of Junior

MESERVE, GEORGE HARRIS, Jr., Medford, Mass. (Age 26, b. Boston, Mass.) Graduate of Northeastern University in 1925. Experience: chief survey engineer, Charles River Reclamation Project at Milford and Bellingham, June to September, 1925; draftsman, Boston City Planning Board, September to December, 1925; chief of party, Hartley L. White, Braintree, January to August, 1926; chief of party, A. C. Peters, at Medford, August to November, 1926; instructor of drawing, Northeastern University, November, 1926, to date. Refers to *W. J. Alcott, H. B. Alvord, G. B. Gee, J. W. Ingalls, W. E. Nightingale.*

NIECHCAY, FRANK K., Arlington Heights, Mass. (Age 29, b. Czernowitz, Austria.) Graduate of Wentworth Institute in 1920. From 1923–26, part time in sewer department, town of Milton, and engineering department, town of Arlington; at present, assistant in town engineer's office, Arlington. Refers to *H. B. Alvord, C. O. Baird, J. W. Ingalls, W. E. Nightingale.*

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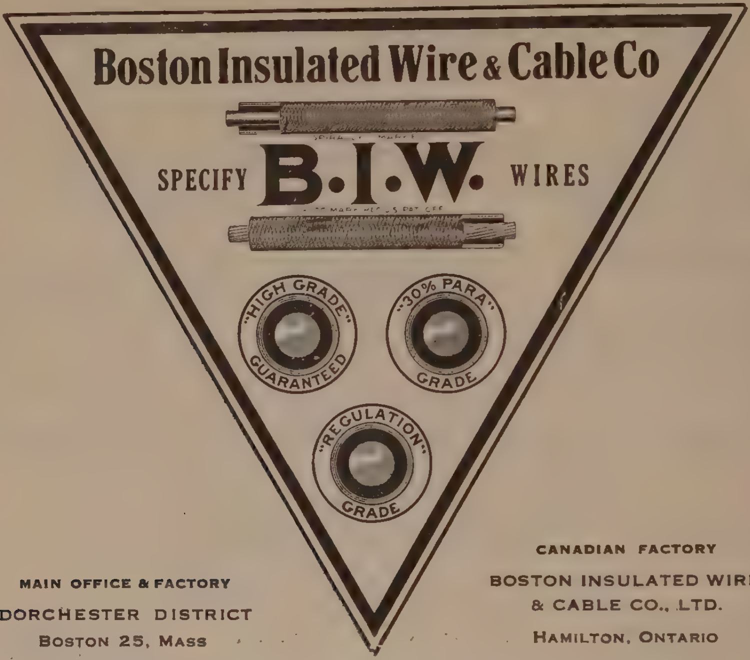

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